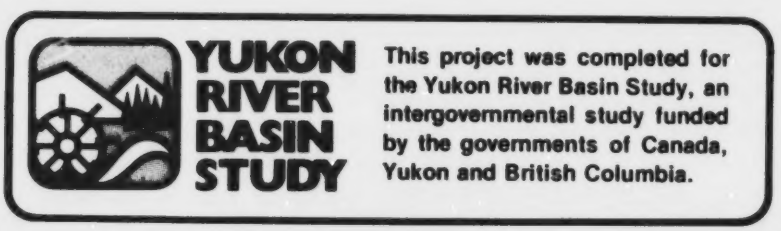
ENVIRONMENT CANADA
INLAND WATERS DIRECTORATE

YUKON RIVER BASIN STUDY
HYDROLOGY WORK GROUP REPORT No. 1

YUKON RIVER BASIN FLOOD RISK STUDY



This project was completed for the Yukon River Basin Study, an intergovernmental study funded by the governments of Canada, Yukon and British Columbia.

the umq group

October, 1983

Underwood McLellan Ltd.

Yukon River Basin Flood Risk Study. October 1983. Underwood McLellan Ltd., Vancouver

Project Report: Hydrology No. 1

Environment Canada, Inland Waters Directorate

REVIEW

by W.G. Whitley
January 31, 1984

SECTION 1

SUMMARY

1.1 INTRODUCTION

This study, to assess the risk of flooding in the Yukon River Basin, was undertaken for Environment Canada, Inland Waters Directorate on behalf of the Yukon River Basin Committee. The objectives of the study were to provide a general overview of flooding in the basin, identify flood-prone areas, determine the causes of flooding, assess the flood control benefits to be derived from reservoir storage or diversion schemes and recommend flood forecasting techniques.

1.2 STUDY AREA

The Yukon River rises in northern British Columbia and flows in a generally northwesterly direction across the Yukon, through Alaska, and discharges into the Bering Sea. The study region is the watershed of the main stem of the Yukon River in Canada, an area of some 295,000 square kilometres. The watershed of the Porcupine River, which joins the Yukon in Alaska, is excluded.

The study area lies in the Northern Plateau and Mountain area of the Canadian Cordillera. It is bounded on the northeast by the Selwyn and Ogilvie Mountains and on the southwest by the Coast and St. Elias Mountains. The St. Elias Mountains are the highest in Canada and are largely covered by glaciers. Forest growth covers the valley floors and extends up the hillsides to the treeline at elevation 1,200 to 1,300 metres.

Climate is characterized by semi-arid conditions in the plateau region, with an increase in precipitation at higher elevations. The southern part of the area is slightly warmer in winter and cooler in summer than the northern region. Mean daily temperatures range from 15°C in July to -30°C in January. Mean annual precipitation on the plateau ranges from 250 mm to 325 mm.

1.3 HYDROLOGY

Principal tributaries to the Yukon River are the Teslin, Pelly, White and Stewart Rivers. There are large lakes in the headwaters of the Yukon and Teslin Rivers which have a regulating effect on flows.

The Water Survey of Canada (WSC) maintains a series of water level gauging stations in the study area. The United States Geological Survey has a station on the Yukon River at Eagle, Alaska. The period of record varies; the longest being since the mid-1940's.

The monthly mean discharges in those rivers which drain the area to the east of the Yukon River are highest during June. On the Yukon River, upstream of Carmacks, and on the tributaries draining to the Yukon River from the west, the highest mean monthly discharges occur during July or August. This late runoff is due to the regulating effects of significant lake storage and the glacier-melt origin of the runoff in many of the headwaters streams. The mean annual runoff in the major rivers is fairly uniform throughout the Yukon River Basin, ranging from eight to twelve cubic metres per second per 1,000 square kilometres of drainage area.

Flood flows in the study area have been estimated on the basis of a regional analysis considering the following region definition:

Region 1	The main stem of the Yukon River.
Region 2	Tributaries having their origin in the Ogilvie and Selwyn Mountains.
Region 3	Headwaters tributaries of the Yukon River upstream of Carmacks.
Region 4	The White River system - excluded from the analysis because of lack of data.

The results of the regional flood frequency analysis are shown graphically on Figure 3 and summarized in the following tabulation. Values for the Mean Annual Flood (MAF) and the 1:100 year flood are for the maximum daily flow in cubic metres per second per 1,000 square kilometres of drainage area.

Regional MAF and 1:100 Year Unit Flood Flows

Region	Drainage Area (km^2)	Maximum Daily Flow ($m^3/s/1,000\ km^2$)	
		MAF	1:100 Year
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	200,000	27.6	59.4
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	4,000	38.4	82.6
	10,000	35.4	76.0
	20,000	33.2	71.4
	40,000	31.2	67.1

1.4 RIVER CHANNEL HYDRAULICS

Average gradients on the Yukon River (Whitehorse to Eagle), Teslin River (Teslin Lake to Yukon River), Pelly River (Ross River to Yukon River) and the Stewart River (Mayo to Yukon River) are in the range of 0.4 to 0.6 metres per kilometre. Gradients are fairly uniform throughout the length of the rivers. There are a few rapids sections; the most notable being Miles Canyon near Whitehorse and Five Finger and Rink Rapids, all on the Yukon River, and Granite and Bradens Canyons on the Pelly River. The fall in the river at each of these locations is limited to a few metres.

Channel cross-sections and stage-discharge curves are available at the various WSC gauging stations. On the Yukon River, the difference in stage between the Mean Annual Flood and the 1:100 year open water flow varies from 0.5 metres at Whitehorse to 4.0 metres at Eagle, Alaska. Variations on the Teslin, Pelly and Stewart Rivers range from 1.5 to 3.3 metres.

Average channel velocities for a flow corresponding to the Mean Annual Flood are 2.0 to 2.5 metres per second on the Yukon River. Lower velocities (1.5 to 2.0 metres per second) are experienced in the upper reaches of the Teslin, Pelly and Stewart Rivers.

1.5 CAUSES OF FLOODING

Peak flood stages on the rivers and streams in the Yukon River Basin can result from snowmelt runoff, rainstorm events, a combination of rainfall on snowmelt, ice jams, or glacier melt.

Spring Runoff

The lower portions of the Yukon River, downstream of the Teslin River confluence, and the Pelly, Teslin and Stewart Rivers all experience peak flows during the spring runoff period. These peak flows are due primarily to snowmelt; however, the effects of rainfall on snowmelt are more pronounced as the watershed size decreases.

Rainstorm Events

The smaller watersheds (less than 10,000 square kilometres in area) can experience peak floods resulting from summer rainstorms. The rainfall events are more significant in producing peak floods in the higher watersheds.

Glacier Melt

The peak flows on tributaries having their origin in the St. Elias Mountains result from glacier melt. These can be either the result of runoff of meltwater peaks during late July and

August, or from the occasional release of ponding resulting from the temporary closing-off of streams by surging glaciers (jökulhlaups).

Ice Jams

Increased water levels resulting from ice jams affect only relatively short reaches of a river. However, particularly on the Yukon River, ice jams have been known to occur at many locations. Ice jam formation is difficult to predict and the rise in water level behind the jam is rapid. There are three types of ice jam that occur in the study area:

Floating Ice Jams, caused by broken ice piling up on, and in front of, a solid ice sheet - typical of those occurring on the Yukon River downstream of Dawson.

Grounded Ice Jams, where ice floes and broken ice are temporarily impeded in their downstream movement by some obstruction and the accumulation extends to the bottom of the channel - typical of the problems at Rock Creek on the Klondike River.

Ice Dams, caused by the accumulation of slush and frazil ice at the leading edge of a solid ice cover during the freeze-up period - typical cause of flooding in the Marwell area of Whitehorse.

Spring Break-up Process

Spring break-up on the Yukon River proceeds in a general south to north direction; however, this progression is not continuous. Rather, the break-up occurs in a series of reaches along the river; the upstream or southern end of each reach having open water, followed by a section of broken ice leading into a downstream solid ice cover. During break-up, the smaller tributaries start to flow first and shore leads develop on the receiving watercourses. The general progression of break-up on the Yukon River is:

- Whitehorse to Carmacks, except Lake Laberge.
- Downstream of the Klondike River (Dawson).
- Between the White and Klondike Rivers.
- Between Carmacks and the Pelly River.
- Between the Pelly River and the White River.

1.6 FLOODING OF SETTLED AREAS

Early settlement of the Yukon Territory relied upon water as the basis for transportation. Thus, most of the settled areas were initially located along the major rivers and on the shores of lakes. While many of these settlements are abandoned today, those that remain are essentially centred around their original locations. The affected communities and the principal causes of flooding are:

Dawson City - high water levels have been experienced as a result of floating ice jams on the Yukon River downstream of Dawson and on the Klondike River at/near the mouth, as well as from open water flows on the Yukon River.

Rock Creek - high water levels have been due to grounded ice jams on the Klondike River in the vicinity of the community.

Mayo - flooding has resulted from high water levels on the Mayo River caused by ice jams at the mouth and high water levels on the Stewart River from peak open water spring runoff events.

Pelly Crossing - no known flooding of the community, although it was reported that there was one year when the water overflowed the left bank and crossed a low section of the highway south of the village.

Carmacks - some flooding reported in the past. The native community on the right bank is slightly lower than the opposite village. Ice jams are infrequent.

Ross River - low-lying areas have been subject to flooding by open water spring runoff events.

Whitehorse - recent flooding appears to be limited to the Marwell area where low-lying ground is affected by high water levels resulting from ice dam formation on the Yukon River during freeze-up.

Teslin - high levels on Teslin Lake have caused flooding of low-lying areas of the community.

1.7 OTHER FLOOD-PRONE AREAS

The lack of detailed topographic information and the relatively small difference in river stage between the Mean Annual Flood level and the 1:100 year flood level (0.5 to 4.0 metres) makes the identification and delineation of floodplains outside the settled areas difficult. The following are general comments regarding flooding along the principal tributaries in the Yukon River Basin:

Yukon River - Ice jams have been known to occur at many locations. No floodplain areas of significant extent exist between Whitehorse and the Teslin River confluence. Downstream of this location there are limited areas at tributary confluences that are subject to flooding; the most extensive of which is at the mouth of the White River. In the reach between the Stewart River and a point about 25 kilometres downstream, there are numerous locations where there is a small side channel to the main river. These intervening areas (and the many islands elsewhere along the river) are likely subject to flooding.

Teslin River - There is very little land in the floodplain. Ice jams are not common. An earth slide on the Teslin River, some 100 kilometres downstream of Johnson Crossing, was reported to have caused high water levels in 1963.

Pelly River - Ice jams are uncommon. The reaches from Ross River to the MacMillan River confluence and from Pelly Crossing to Bradens Canyon have a broad, U-shaped valley with numerous old abandoned sections of channel, oxbow cutoffs and small active side channels. The floodplain is fairly extensive in these valley sections which are one to two kilometres wide. There is very little floodplain land in other reaches of the river.

Stewart River - There is little knowledge of ice jams on this river. Upstream of Mayo, between Sixteen Mile and Stewart Crossing and from the McQuesten River to a point 20 kilometres upstream, the valley is U-shaped, two to four kilometres wide and contains numerous oxbows and active side channels. Much of the valley bottom land is floodplain. There is also an extensive floodplain at the mouth of the Stewart River.

Klondike River - The lower reach of the Klondike River, from Flat Creek to the Yukon River, flows in a wide, relatively shallow channel. A small amount of the valley bottom is in the floodplain; however, grounded ice jams have been known to occur frequently at a number of locations.

1.8 FLOOD FORECASTING

A watershed model to simulate the snowmelt process and the resulting runoff has been used by Indian and Northern Affairs Canada to successfully predict water levels at Mayo and Ross River for the past few years. Use of this model should continue. There are no other locations in the study area where use of this model is presently required.

Ice jam formation is impossible to predict with any degree of certainty and no "forecasting" methods can be suggested. Areas of concern known to be subject to ice jams should be watched during break-up, including aerial reconnaissance of the river upstream and downstream to identify ice jam formation.

1.9 FLOOD DAMAGE REDUCTION

Recognizing that there are some areas in the Yukon River Basin where periodic flooding will occur, the following should be addressed.

- Provision of some reasonable level of flood protection for existing developments located on floodplains.
- Establishment of development strategies that prevent future uncontrolled building on a floodplain.

Flood Protection

To date, flood protection in the study area has been limited to dyking along the river banks to impede the encroachment of rising flood waters on communities such as Dawson, Mayo and Ross River. Dyking was often done, or added to, at the time of rising river stage. The consequences when a dyke is overtopped are well understood, particularly by the residents of Dawson who have experienced such an occurrence more than once in the past.

Flood flow reduction provides a more secure means of flood protection than that afforded by dyking. A number of potential water resource development projects in the study area have previously been identified. While the main purpose of these projects has generally been for hydroelectric power generation, some could be operated in such a manner as to achieve a significant reduction in flood flows. In order to assess the effectiveness of such projects in reducing floods, the following "hypothetical" control cases were analysed.

Yukon River	Reduction of the 1:100 year flows at Carmacks and at Pelly Crossing by 50 percent.
Teslin River	Reduction of the 1:100 year flow at Johnsons Crossing by 50 percent.
Stewart River	Reduction of the 1:100 year flow at Mayo by 25 percent.

The greatest effect on flood stage reduction obviously occurs immediately downstream of the point of control. As the amount of unregulated intervening inflow increases, the reduction in stage at points farther down the river from the control location becomes less. For example, the regulation case analysed for the Yukon River results in reductions of the 1:100 year open water flood stage of 2.7, 1.6 and 0.9 metres at Carmacks, Dawson and Eagle, respectively.

Development Strategies

Development of lands adjacent to rivers and lakes must recognize the inherent dangers of encroachment on the floodplain. Control of development on floodplains requires a recognition of the problem by all levels of government and the establishment of effective land use planning guidelines and regulations. Some of the basic factors to be considered in such regulations are:

- The level of protection to be adopted, i.e. the 1:100 or 1:200 year event.

- The designation of a "floodway" as being the main river channel, plus that part of the floodplain which must remain free of obstructions in order to convey the design flood.

- Definition of the types of development that can take place in the floodplain area outside the floodway.

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the uma group

October, 1983

Underwood McLellan Ltd.

Underwood McLellan Ltd.

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1983 11 21

Environment Canada
Inland Waters Directorate
Water Planning and Management Branch
502 - 1001 West Pender Street
Vancouver, B.C.
V6E 2M9

Attention: Mr. R.O. Lyons, P.Eng., Acting Head,
Systems and Regulation Division

Dear Sir

Re: Yukon River Basin Flood Risk Study

Pursuant to our Contract No. OSB83-00263 with Supply and Services Canada, we are pleased to submit our final report on the study to assess the flood risks along the rivers of the Yukon River Basin.

The opportunity to work with you on this study has been appreciated. We wish to acknowledge the valuable assistance of personnel from the Water Survey of Canada and the Water Planning and Management Branch of Environment Canada and the numerous residents of the Yukon who contributed to the study.

Yours truly

UNDERWOOD McLELLAN LTD.

J.A. Knowles, P.Eng.
Director, Water
Resources Division
/cs

Cable: UMAGROUP

This report was funded by the Yukon River Basin Committee under the terms of "An Agreement Respecting Studies and Planning of Water Resources in the Yukon River Basin" between Canada, British Columbia and Yukon. The views, conclusions and recommendations are those of the author and not necessarily those of the Yukon River Basin Committee, or the Governments of Canada, British Columbia and Yukon.

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SECTION 1

SUMMARY

1.1 INTRODUCTION

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Rock Creek - high water levels have been due to grounded ice jams on the Klondike River in the vicinity of the community.

Mayo - flooding has resulted from high water levels on the Mayo River caused by ice jams at the mouth and high water levels on the Stewart River from peak open water spring runoff events.

Pelly Crossing - no known flooding of the community, although it was reported that there was one year when the water overflowed the left bank and crossed a low section of the highway south of the village.

Carmacks - some flooding reported in the past. The native community on the right bank is slightly lower than the opposite village. Ice jams are infrequent.

Ross River - low-lying areas have been subject to flooding by open water spring runoff events.

Whitehorse - recent flooding appears to be limited to the Marwell area where low-lying ground is affected by high water levels resulting from ice dam formation on the Yukon River during freeze-up.

Teslin - high levels on Teslin Lake have caused flooding of low-lying areas of the community.

1.7 OTHER FLOOD-PRONE AREAS

The lack of detailed topographic information and the relatively small difference in river stage between the Mean Annual Flood level and the 1:100 year flood level (0.5 to 4.0 metres) makes the identification and delineation of floodplains outside the settled areas difficult. The following are general comments regarding flooding along the principal tributaries in the Yukon River Basin:

Yukon River - Ice jams have been known to occur at many locations. No floodplain areas of significant extent exist between Whitehorse and the Teslin River confluence. Downstream of this location there are limited areas at tributary confluences that are subject to flooding; the most extensive of which is at the mouth of the White River. In the reach between the Stewart River and a point about 25 kilometres downstream, there are numerous locations where there is a small side channel to the main river. These intervening areas (and the many islands elsewhere along the river) are likely subject to flooding.

Teslin River - There is very little land in the floodplain. Ice jams are not common. An earth slide on the Teslin River, some 100 kilometres downstream of Johnson Crossing, was reported to have caused high water levels in 1963.

Pelly River - Ice jams are uncommon. The reaches from Ross River to the MacMillan River confluence and from Pelly Crossing to Bradens Canyon have a broad, U-shaped valley with numerous old abandoned sections of channel, oxbow cutoffs and small active side channels. The floodplain is fairly extensive in these valley sections which are one to two kilometres wide. There is very little floodplain land in other reaches of the river.

Stewart River - There is little knowledge of ice jams on this river. Upstream of Mayo, between Sixteen Mile and Stewart Crossing and from the McQuesten River to a point 20 kilometres upstream, the valley is U-shaped, two to four kilometres wide and contains numerous oxbows and active side channels. Much of the valley bottom land is floodplain. There is also an extensive floodplain at the mouth of the Stewart River.

Klondike River - The lower reach of the Klondike River, from Flat Creek to the Yukon River, flows in a wide, relatively shallow channel. A small amount of the valley bottom is in the floodplain; however, grounded ice jams have been known to occur frequently at a number of locations.

1.8 FLOOD FORECASTING

A watershed model to simulate the snowmelt process and the resulting runoff has been used by Indian and Northern Affairs Canada to successfully predict water levels at Mayo and Ross River for the past few years. Use of this model should continue. There are no other locations in the study area where use of this model is presently required.

Ice jam formation is impossible to predict with any degree of certainty and no "forecasting" methods can be suggested. Areas of concern known to be subject to ice jams should be watched during break-up, including aerial reconnaissance of the river upstream and downstream to identify ice jam formation.

1.9 FLOOD DAMAGE REDUCTION

Recognizing that there are some areas in the Yukon River Basin where periodic flooding will occur, the following should be addressed.

- Provision of some reasonable level of flood protection for existing developments located on floodplains.

- Establishment of development strategies that prevent future uncontrolled building on a floodplain.

Flood Protection

To date, flood protection in the study area has been limited to dyking along the river banks to impede the encroachment of rising flood waters on communities such as Dawson, Mayo and Ross River. Dyking was often done, or added to, at the time of rising river stage. The consequences when a dyke is overtopped are well understood, particularly by the residents of Dawson who have experienced such an occurrence more than once in the past.

Flood flow reduction provides a more secure means of flood protection than that afforded by dyking. A number of potential water resource development projects in the study area have previously been identified. While the main purpose of these projects has generally been for hydroelectric power generation, some could be operated in such a manner as to achieve a significant reduction in flood flows. In order to assess the effectiveness of such projects in reducing floods, the following "hypothetical" control cases were analysed.

Yukon River	Reduction of the 1:100 year flows at Carmacks and at Pelly Crossing by 50 percent.
Teslin River	Reduction of the 1:100 year flow at Johnsons Crossing by 50 percent.
Stewart River	Reduction of the 1:100 year flow at Mayo by 25 percent.

The greatest effect on flood stage reduction obviously occurs immediately downstream of the point of control. As the amount of unregulated intervening inflow increases, the reduction in stage at points farther down the river from the control location becomes less. For example, the regulation case analysed for the Yukon River results in reductions of the 1:100 year open water flood stage of 2.7, 1.6 and 0.9 metres at Carmacks, Dawson and Eagle, respectively.

Development Strategies

Development of lands adjacent to rivers and lakes must recognize the inherent dangers of encroachment on the floodplain. Control of development on floodplains requires a recognition of the problem by all levels of government and the establishment of effective land use planning guidelines and regulations. Some of the basic factors to be considered in such regulations are:

- The level of protection to be adopted, i.e. the 1:100 or 1:200 year event.

- The designation of a "floodway" as being the main river channel, plus that part of the floodplain which must remain free of obstructions in order to convey the design flood.

- Definition of the types of development that can take place in the floodplain area outside the floodway.

SECTION 2

INTRODUCTION

2.1 AUTHORIZATION

The authority for work on this assignment is contained in Contract No. OSB83-00263, dated July 14, 1983, between Supply and Services Canada and Underwood McLellan Ltd. The designated Scientific Authority was Environment Canada, Inland Waters Directorate.

2.2 TERMS OF REFERENCE

The detailed Terms of Reference for the study are contained in the Contract. The objective of the study is to provide a general overview of flooding in the Yukon River Basin. This information would be used to assess the risk of flooding at any proposed development along the river system and determine the potential flood control benefits to be derived from any proposed reservoir storage or diversion projects. More specifically, the following items were included in the study.

- Determine the location and approximate extent of floodplains.
- Categorize the flood prone areas by cause of innundation (ice jam, open water flow, etc.).
- Estimate the effectiveness of peak flow reductions associated with major storage or diversion projects by assessing the resulting reduction in the extent of flooding at downstream locations.
- Determine the risk of flooding at existing and planned communities.
- Recommend forecasting techniques for spring runoff and ice jam flooding.

2.3 THE STUDY AREA

The Yukon River rises in northern British Columbia and flows in a generally northwesterly direction across the Yukon Territory, through Alaska, and discharges into the Bering Sea. Covering an area of approximately 850,000 square kilometres, the Yukon River Basin is the fifth largest drainage area on the North American continent.

In Canada, the Basin is divided into two drainage areas by the Ogilvie and Wernecke Mountains. The larger southern region is drained by the main stem of the Yukon River, while the northern

region contains the Porcupine River. The drainage area of the main stem of the Yukon River, at the point where it enters Alaska, is about 295,000 square kilometres. The principal rivers in the Basin are shown on Figure 1.

More specifically, the area which is the subject of this study covers the following river systems:

- Yukon River, from Marsh Lake to the Alaska border.
- Teslin River, from Teslin Lake to the Yukon River.
- Pelly River, from Ross River to the Yukon River.
- Stewart River, from Mayo to the Yukon River.
- A number of smaller tributaries which will serve as typical examples of flooding problems which can result from certain conditions particular to each selected watershed.

2.3.1 Physiography

That portion of the Yukon River drainage area which is included in this study lies in the Northern Plateau and Mountain area of the Canadian Cordillera. In general terms, the area is bounded on the northeast by the Selwyn and Ogilvie Mountains and on the southwest by the Coast and St. Elias Mountains. The St. Elias Mountains are the highest in Canada (Mount Logan, elevation 6,050 metres) and are largely covered with glaciers. The intervening area is an elevated or upland zone, referred to as the Yukon Plateau. The northwest trending Tintina and Shakwak Trenches are prominent regional physiographic lineaments. The Tintina Trench is developed along the trace of a major fault running from Watson Lake in the southeast, to Ross River, Stewart Crossing and crossing into Alaska just north of the Yukon River.

2.3.2 Regional Geology

The Coast and St. Elias Mountains bordering the study area consist largely of thick deposits of sedimentary and volcanic rocks, with granitic intrusives. The Ogilvie and Selwyn Mountains are composed primarily of sedimentary rocks, with scattered intrusions of granitic and basic rocks. The Yukon Plateau contains old metamorphic rocks, folded sedimentary rocks, volcanics and instrusives. The topography of the Yukon Plateau represents a maturely eroded surface which was later subjected to regional uplift. This uplift rejuvenated the streams which have since incised themselves into the plateau.

The southern and eastern parts of the study area were covered by the last (Pleistocene) glaciation period. As a result, the surficial materials of the Yukon Plateau are predominately glacial drift, with well-bedded silt deposits at the sites of proglacial lakes. The western limit of the last ice sheet was roughly 137° west longitude. The area subjected to glaciation includes the Yukon River upstream of Fort Selkirk, all of the eastern tributaries from the Pelly River to the headwaters, and the Stewart River upstream of Stewart Crossing.

2.3.3 Vegetation

Forest growth in the study area covers the valley floors and extends up the hillsides to the treeline at elevation 1,200 to 1,300 metres. Above the treeline, the uplands and some of the higher valleys support varieties of dwarf grasses, moss and heather.

The most abundant and most economically important tree is the white spruce. It is found on the well drained parts of the valley bottoms and on the lower portions of the hillsides. Black spruce grow on the poorly drained areas of the valley flats and on ground which is permafrost affected. Alpine fir (balsam fir) are found at higher elevations, near the treeline.

Aspen poplar and balsam poplar are the most common deciduous trees. Other varieties include alder and white birch. Willow is found along the banks of streams and is mixed with dwarf birch near the treeline.

2.3.4 Climate

The area is dominated by continental climatic influences. The climate is characterized by semi-arid conditions in the Yukon Plateau region and by heavier precipitation in the mountains. Topography is the most important influence on the climate of the Basin. The St. Elias and Coast Mountains form a generally continuous and effective barrier against the moderating influence of maritime air masses from the Pacific Ocean. On the other hand, the Selwyn and Ogilvie Mountains have a tempering effect on the climate by preventing, to a certain extent, the influx in the winter of extremely cold continental Arctic air from the north and northeast.

Temperature

Mean daily temperatures at seven locations in the study area are shown on the following tabulation. The coldest months are December, January, and February; the warmest being June, July, and August.

The southern portion of the area (Whitehorse, Teslin) is slightly warmer in winter and cooler in summer than the northern area.

Mean Daily Temperatures - Yukon Territory (°C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Whitehorse	-21	-13	- 8	0	7	12	14	13	8	1	- 9	-17	-1.2
Teslin	-22	-14	- 8	- 1	6	11	13	12	7	0	- 9	-17	-1.8
Carmacks	-28	-19	-12	0	7	13	15	12	7	- 2	-14	-24	-3.8
Ross River	-29	-21	-14	- 2	5	11	13	11	5	- 3	-18	-27	-5.7
Fort Selkirk	-30	-22	-13	0	7	13	15	12	7	- 3	-16	-27	-4.7
Mayo	-29	-20	-12	0	8	13	15	13	7	- 2	-15	-24	-4.0
Dawson	-31	-24	-15	- 2	8	14	16	13	7	- 4	-17	-26	-5.1

There is little variation in the maximum recorded temperature throughout the area. Extreme lows vary from -52.2°C at Whitehorse to -62.2°C at Mayo.

Temperature Extremes - Yukon Territory (°C)

	Daily Minimum		Daily Maximum	
	Temp.	Month	Temp.	Month
Whitehorse	-52.2	January	34.4	June
Teslin	-52.8	January	33.3	June
Carmacks	-57.8	January	35.0	June
Ross River	-59.4	January	33.3	June
Fort Selkirk	-60.0	February	35.0	June
Mayo	-62.2	February	36.1	June
Dawson	-58.3	February	35.0	June

Precipitation

Precipitation at seven locations in the study area is as follows:

Precipitation in the Yukon Territory (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Whitehorse	18	13	13	10	13	31	34	38	30	21	20	20	261
Teslin	28	20	23	12	17	27	38	37	37	33	26	31	327
Carmacks	18	12	11	7	16	37	42	34	25	18	19	15	254
Ross River	19	16	15	12	15	32	42	32	23	16	23	19	264
Fort Selkirk	20	14	12	11	19	34	50	33	25	21	24	23	286
Mayo	18	17	10	9	20	35	52	42	30	28	24	23	306
Dawson	16	16	10	10	21	39	47	44	28	29	21	25	306

Precipitation is highest in the southeast part of the study area (Teslin) and lowest in the Whitehorse, Carmacks area. All the meteorologic stations tabulated are located in the lower parts of the Yukon Plateau and therefore the increase in precipitation with increasing elevation is not evident.

Rainfall accounts for close to 60 percent of the total precipitation. The maximum recorded 24 hour rainfall is 91.4 mm at Quiet Lake in the headwaters of the Big Salmon River. The second highest daily rainfall is 52.8 mm at Dawson.

2.4 STUDY METHODOLOGY

The technical approach or methodology used in the study involved the following:

- Collection and review of all relevant reports and data pertaining to the study area.
- Study of 1:50,000 topographic mapping and aerial photography to identify low-lying areas along the rivers that could be subject to flooding.
- Development of cross sections and stage discharge relationships at streamflow stations from Water Survey of Canada (WSC) data.
- Hydrologic analyses to determine the 1:100 year flood flow and stage at each gauging station.
- Archives research and interviews with local residents to obtain information on historic floods and the locations of ice jams and the areas frequently subject to flooding.
- Ground reconnaissance of the study area to inspect typical areas subject to flooding and assess the relationship between river stage and degree of flooding.
- Review of oblique photographs taken during the break-up of the Yukon River in 1982 and 1983 in order to identify locations of ice jams.
- Office studies of watershed hydrology and river hydraulics.

2.5 AVAILABLE DATA

Available data on the area which is relevant to this study includes:

- Climatic information (rainfall, snowfall and temperature) for a number of meteorologic stations.

- Streamflow and lake level records.

- Topographic maps at scales of 1:50,000, 1:250,000, 1:500,000 and 1:1,000,000 published by Energy, Mines and Resources Canada. The 1:50,000 coverage is unavailable for a portion of the Teslin River.

- Numerous geologic reports and maps.

- Flow-frequency analyses for data from the WSC gauging stations.

2.6 PREVIOUS REPORTS

Previous reports dealing with flooding in the study area include:

- "Yukon Flood Study", May 1974, by Foundation of Canada Engineering Corporation Limited.

- "Yukon River Ice Study, Dawson, Yukon Territory", October 1976, by Fenco Consultants Ltd.

- "Historical Review of Dawson City Flood Data 1898 - 1975", March 1981, by Dawson City Museum and Historical Society.

- "Dawson Flood Study - Ice Jam of May 3, 1979, 1980, and 1981 Breakup", by Mel Orecklin, P.Eng., Department of Indian & Northern Affairs.

- "A Survey of the Timing and Progression of the Ice Break-up on the Yukon River, 1982", by T.D. Kent.

- "A Survey of the Timing and Progression of the Ice Break-up on the Yukon River, 1983", by T.D. Kent.

- "Magnitude of Floods, British Columbia and Yukon Territory", September 1982, by Environment Canada, Inland Waters Directorate.

These and other pertinent reports are listed in the bibliography at the end of this report.

2.7 STUDY AREA RECONNAISSANCE

A reconnaisance of the study area was carried out during August 25 to 31, 1983. Detailed notes on activities are included in Appendix A. The following is a summary of the areas visited:

August 25	Yukon River from Whitehorse to Upper Laberge, Lake Laberge.

August 26	Whitehorse to Johnsons Crossing, Teslin and return to Whitehorse.
August 27	Whitehorse to Carmacks, Faro, Ross River and return to Carmacks.
August 28	Carmacks to Five Finger Rapids, Yukon Crossing, Minto, Pelly Crossing, Pelly Farm, Stewart Crossing and Dawson.
August 29	Dawson City area, including Klondike River and Rock Creek.
August 30	Dawson to Mayo, Stewart Crossing, Granite Canyon, Pelly Crossing, Carmacks and Whitehorse.
August 31	Whitehorse area.

Principal activities undertaken during the reconnaissance include:

- Measurement of river widths with a rangefinder and visual estimation of bank heights above present water level at accessible locations along the rivers. Oblique color photographs at each location.
- Reading of WSC gauges to obtain estimates of river flow at the time of the reconnaissance.
- Examination of the river banks at accessible sites for evidence of high water marks and ice action.
- Interviews with local residents.

2.8 ARCHIVES RESEARCH

Research of the archives in Dawson City has been carried out by the Dawson City Museum and Historical Society. The results of this research are documented in the report cited in Section 2.6. During the course of this study the archives in Whitehorse were researched to identify accounts of flooding in the Yukon River Basin. The results of this work are contained in Appendix B.

SECTION 3

HYDROLOGY

3.1 HYDROMETRIC GAUGING STATIONS

The Water Survey of Canada (WSC) maintains a series of lake and river level gauging stations in the study area. The period of record varies; the longest being since the mid-1940's. There is also a station on the Yukon River at Eagle, Alaska which has been operated by the United States Geological Survey since June 1950. This station is located 18 kilometres downstream of the Alaska - Yukon Territory border.

3.2 MEAN ANNUAL RUNOFF

The monthly mean discharges in those rivers which drain the area to the east of the Yukon River are highest during June. On the Yukon River upstream of Carmacks, and on the tributaries draining to the Yukon River from the west, the highest mean monthly discharges occur during July or August. This late runoff is due to the regulating effects of significant lake storage and the glacier-melt origin of the runoff in many of the headwaters streams. The mean annual runoff in the major rivers is fairly uniform throughout the Yukon River Basin, ranging from eight to twelve cubic metres per second per 1,000 square kilometres of drainage area. Selected values are given in the following tabulation.

Mean Annual Runoff (MAR) - Yukon River Basin

Location	Drainage Area (km)	Mean Annual Runoff ($m^3/s/1,000\ km^2$)
Yukon R. at Whitehorse	19,400	12
Yukon R. above Frank Cr.	30,800	10
Yukon R. at Carmacks	81,800	9
Yukon R. above White R.	150,000	8
Yukon R. at Dawson	264,000	8
Teslin R. near Teslin	30,300	10
Big Salmon R. near Carmacks	6,760	10
Pelly R. at Pelly Crossing	49,000	8
Stewart R. at the mouth	51,000	9

3.3 AVAILABLE FLOOD FLOW DATA

The available flood flow data for the long term stations are shown on Table 3-1. The tabulated data are maximum daily flows. Data for 1981 and 1982 are shown for information only and were not used in the computation of the mean annual flood or in the flow frequency analysis.

3.4 FLOW-FREQUENCY ANALYSES

Maximum daily flow data for those gauging stations in the Yukon River Basin with nine or more years of records were subjected to flow-frequency analyses using the Flood Damage Reduction Program Flood Frequency Analysis (FDRPFFA) computer program developed by Environment Canada, Inland Waters Directorate (IWD). Copies of the printouts of the analysis for each of the stations were provided by IWD. These anlayses considered the historic data period up to, and including, 1980. The analysis of data for the station at Eagle, Alaska, was carried out by UMA, using the FDRPFFA program.

Shown on Table 3-1 are the values for the mean annual flood and the 1:100 year estimated flood flow at each of the gauging stations. These values have been derived from the flow frequency analysis of data for each station and not from the regional analysis. A copy of the printout for this analysis is included at the end of this section. Data for the years 1981 and 1982 were excluded from the analyses. The 1:100 year flood flow is that derived from the three parameter lognormal distribution.

3.5 FLOOD HYDROGRAPHS

Hydrographs for 1964 for the following WSC stations are shown on Figure 2.

- Yukon River at Dawson
- Yukon River above White River
- Yukon River at Carmacks
- Stewart River at the mouth
- Pelly River at Pelly Crossing
- Teslin River near Whitehorse

The flood of record on the lower part of the Yukon River and on the Stewart River occurred in 1964. The timing of the peak flows on the lower part of the Yukon and on the Stewart and Pelly Rivers was coincident (June 11 to 12), while that on the Teslin River occurred slightly later (June 20).

The hydrograph shapes for the Yukon River at Dawson, the Stewart River at the mouth and the Pelly River at Pelly Crossing are characterized by a sharp rising limb covering a period of two to three weeks, followed by a two to three month recession limb. Minor rainfall peaks appear on the recession limb. On the Teslin River, the rising limb has a longer duration and the hydrograph is quite smooth as a result of the regulating effect of Teslin Lake.

3.6 REGIONAL FLOOD FREQUENCY

A regional analysis was undertaken in order to develop relationships between flood magnitude and drainage areas for

various parts of the Yukon River Basin. These relationships can be used to estimate the maximum daily flood flows at ungauged locations within the study area.

3.6.1 Region Definition

The Yukon River Basin was divided into the following four regions:

- The main stem of the Yukon River
- Tributaries rising in the Ogilvie and Selwyn Mountains
- Headwater tributaries of the Yukon River
- The White River system

The area of the White River system was excluded because of lack of records. The gauging stations considered in the analysis of the other three regions were:

Region 1 — Yukon River

a) Yukon River at Eagle, Alaska
b) Yukon River at Dawson
c) Yukon River at Stewart River
d) Yukon River above White River
e) Yukon River at Carmacks
f) Yukon River above Frank Creek
g) Yukon River at Whitehorse

Region 2 — Ogilvie - Selwyn Mountains

a) Stewart River at Mayo
b) Stewart River at the mouth
c) Stewart River at Stewart Crossing
d) Pelly River at Pelly Crossing
e) Pelly River below Vangorda Creek
f) Pelly River at Ross River
g) Ross River at Ross River
h) Klondike River above Bonanza Creek

Region 3 — Headwaters

a) Teslin River near Teslin
b) Teslin River near Whitehorse
c) M'Clintock River near Whitehorse
d) Wheaton River near Carcross
e) Takhini River at Kusawa Lake
f) Takhini River near Whitehorse
g) Big Salmon River near Carmacks

Region definition was based on a review of the variation in climatic and physiographic characteristics throughout the Basin. In carrying out the regional analysis, tests were

performed to determine if the stations in each region were statistically homogeneous. The test is based on the 1:10 year flood and the Mean Annual Flood (1:2.33 years) as estimated from the flood frequency curves for each station and determines if the points in the sample set differ in amounts that would not normally be expected by chance.

All stations in Regions 2 and 3 were found to be homogeneous. In Region 1, the Yukon River near Whitehorse and Yukon River above Frank Creek did not pass the test. It was concluded that although these stations correlated well with the other stations in the region when dealing with the Mean Annual Flood, the regulation of the Yukon River at Whitehorse has an effect on the more severe floods. Therefore, curves developed from the regional analysis cannot be used when determining flood flow values in excess of the Mean Annual Flood at points on the Yukon River upstream of Frank Creek.

3.6.2 Flood Flow vs. Drainage Area

The regional analysis was performed using the Mean Annual Flood (MAF) values from the three parameter log normal frequency distribution. Drainage area and MAF values (2.33 years) were correlated and a power log equation relating the two factors were obtained for each region.

Region 1 $MAF = 0.015\ (DA)^{1.05}$ $r = 0.996$

Region 2 $MAF = 0.085\ (DA)^{0.95}$ $r = 0.955$

Region 3 $MAF = 0.081\ (DA)^{0.91}$ $r = 0.983$

The average ratios that a flood of a given return period has to the MAF (Qt/MAF) were determined for each region by analysing the data from the individual station flow frequency analyses. The dimensionless ratio (Qt/MAF) was determined for return periods of 5, 10, 20, 50 and 100 years. The 95 percent confidence bands (equal to two standard deviations) were drawn on the curve for each region. This is considered an acceptable confidence limit for hydrologic analyses.

The relationships between drainage area and MAF, and the flood flow frequency curves, are shown on Figure 3.

RECORDED MAXIMUM DAILY FLOWS (m^3/s) - YUKON RIVER BASIN

RIVER:	Yukon	Yukon	Yukon	Yukon	Yukon	Yukon	Yukon	Stewart	Stewart	Stewart	Stewart	Pelly
LOCATION:	Eagle,	Dawson	Stewart R.	White R.	Carmacks	Frank Cr.	W-horse	Mouth	S. Xing	Mayo	Fraser F.	Pelly Xing
STATION NO:	USGS	09EB001	09EB002	09CD001	09AH001	09AB009	09AB001	0900003	0900002	09DC002	09DC003	09BC001
DRAINAGE AREA (km^2)	294000	264000	251000	150000	81800	30800	19400	51000	35000	31600	30600	49000
1944							631					
1945		6650					481					
1946		7330					518					
1947		7900					473					
1948		7220					555					
1949		7360					467			2460		
1950		6090					504			1510		
1951	5239	4640					487			912		
1952	7787	6140			2200		552			--		
1953	5777	--			1580	821	646			2000		1100
1954	6739	--			1700	660	518			1930		1570
1955	7872	--			1770	699	521			2680		1480
1956	6513	5410			1350	603	445			1950		1740
1957	14725	10600	9910	5270	2510	799	586			3680		4300
1958	5692	5920	4640	2350	1150	606	493			1810		1550
1959	8665	7820	6310	3340	1840	736	541			2630		--
1960	7079	6510	5830	3090	1880	722	558			2310		1230
1961	10400	10100	8980	4980	2590	824	629		3770	3680		2440
1962	13200	10900	10200	7700	3600	736	538		2830	2730		2970
1963	8190	7900	7500	3570	2380	736	609		2370	2270		2460
1964	15400	14900	13300	6850	2890	750	592	5610	4300	4110		4130
1965	10000	6600	5640		1460	592	456	1930	1750	1700		1750
1966	8360	6990		3400	1710	643	459	2240	2210	2020		1670
1967	11400	9830		4900	2450	682	527	2830	2590	2420		2970
1968	8297	7280		3230	1650	657	484	2210	1920	1920		1970
1969	6710	6120		3060	1760	668	507	1870	1870	1830		1370
1970	7650	6970		3540	1380	490	377	2940	2790	2690		2260
1971	8390	7620		3430	1950	818	612	2700	2580	2450		2040
1972	12600	12100		6540	2410	691	535	3570	2920	2860		3430
1973	7620	6800		3260	1800	566	416	2210	2000	1870		1930
1974	6430	6200		3060	1730	643	450	1780		1500		1790
1975	10500	9090		3790	2020	765	564	3960		3110		2590
1976	7960	7530		3850	2250	660	501	1760		1630		1420
1977	8610	7080		3230	2000	793	620	2570		2340		1980
1978	6800	5550		2680	1180	569	419	2160		1800		1510
1979	8240	7340		3750	2250	744	556	2110		2010		2180
1980	6710	6030		2490	1510	657	510	2040		1930	1930	1270
1981	7280	6050		3010	1780	762	635	1530		1460	1460	1440
1982	9288	7100		3310	1610	687	481	1850		1850	1850	1740
MEAN ANNUAL FLOOD:	8600	7650	8030	3970	1960	690	520	2620	2610	2290	--	2110
1:100 YEAR FLOOD:	16700	14500	15900	9740	3650	840	680	8870	4940	4270	--	5610

Notes: 1. The values for the MAF and 1:100 year flood were obtained from the three parameter log normal frequency distribution of the historic data for each station up to, and including, 1980.

2. Since periods of record with varying lengths have been used, the data base is not consistent and the computed values for the MAF and the 1:100 year flood are affected accordingly.

RECORDED MAXIMUM DAILY FLOWS (m^3/s) - YUKON RIVER BASIN

RIVER:	Pelly	Pelly	Ross	Teslin	Teslin	Klondike	Big Salmon	Takhini	Takhini	Mclintock
LOCATION:	Vangorda	Ross	Ross	W-horse	Teslin	Bonanza	Carmacks	W-horse	Kusawa	Whitehorse
STATION NO:	09BC004	09BC002	09BA001	09AF001	09AE001	09EA003	09AG001	09AC001	09AC004	09AB00R
DRAINAGE AREA (km^2)	22100	18400	7250	36500	30300	7800	6760	6990	4070	1700
1944					974					
1945					--					
1946					--					
1947					--					
1948					1370					
1949					1130			487		
1950					651			261		
1951					963			181		
1952					1230			214		
1953					691		258	343	264	
1954					1130			158	156	
1955		1060			1150		264	238		
1956		1010		844	810		184	184	159	28.0
1957		1220		1470	1490		300	272		92.3
1958		589		780	691			159	156	28.6
1959		--		1070	1070			268	253	37.9
1960		705		1090	1090			198	180	39.4
1961		1490		1610	1660			258		--
1962		1580	589	1850	1840		671	297	261	75.6
1963		1200	487	1160	1040			255	251	69.1
1964		2010	--	1720	1710		552	281	279	88.3
1965		934	343	949	875		249	203	186	38.5
1966		847	320	1060	985	433	309	208	204	56.4
1967		1440	510	1430	1320	411	456	246	232	82.4
1968		954	442	915	864	357	271	176		66.0
1969		869	328	1010	934	286	314	276	240	59.5
1970		1020	498	855	799	343	382	137	119	25.9
1971		909	388	1210	1160	476	360	259	227	44.2
1972		1720	742	1540	1510	640	462	200	180	104
1973	889	847	374	1120	1060	--	294	170	152	44.5
1974	963	929	430		900	317	266	225	154	74.2
1975	1330		564		1040	544	314	289	252	47.9
1976	799		297		1290	374	281	220	194	61.7
1977	1090		462		1230	425	264	246	208	40.8
1978	824		278		456	210	297	156	147	27.4
1979	1200		460		1180	408	326	249	201	44.0
1980	753		320		810	360	302	174	159	31.4
1981	900		337		1030	302	269	202	201	46.0
1982	816		298		904	416	352	206	175	52.8
MEAN ANNUAL FLOOD:	1000	1120	435	1200	1090	400	335	235	200	54.5
1:100 YEAR FLOOD:	1550	2230	910	2310	1930	690	690	450	320	160

Notes: 1. The values for the MAF and 1:100 year flood were obtained from the three parameter log normal frequency distribution of the historic data for each station up to, and including, 1980.

2. Since periods of record with varying lengths have been used, the data base is not consistent and the computed values for the MAF and the 1:100 year flood are affected accordingly.

SAMPLE FLOOD FREQUENCY ANALYSIS

YUKON RIVER AT EAGLE ALASKA

YEAR	DATA	ORDERED	RANK	PROB.	RET PERIOD
51	5239.	15400.	1	0.030	33.000
52	7787.	14725.	2	0.061	16.500
53	5777.	13200.	3	0.091	11.000
54	6739.	12600.	4	0.121	8.250
55	7872.	11400.	5	0.152	6.600
56	6513.	10500.	6	0.182	5.500
57	14725.	10400.	7	0.212	4.714
58	5692.	10000.	8	0.242	4.125
59	8665.	9288.	9	0.273	3.667
60	7079.	8665.	10	0.303	3.300
61	10400.	8610.	11	0.333	3.000
62	13200.	8390.	12	0.364	2.750
63	8190.	8360.	13	0.394	2.538
64	15400.	8297.	14	0.424	2.357
65	10000.	8240.	15	0.455	2.200
66	8360.	8190.	16	0.485	2.063
67	11400.	7960.	17	0.515	1.941
68	8297.	7872.	18	0.545	1.833
69	6710.	7787.	19	0.576	1.737
70	7650.	7650.	20	0.606	1.650
71	8390.	7620.	21	0.636	1.571
72	12600.	7280.	22	0.667	1.500
73	7620.	7079.	23	0.697	1.435
74	6430.	6800.	24	0.727	1.375
75	10500.	6739.	25	0.758	1.320
76	7960.	6710.	26	0.788	1.269
77	8610.	6710.	27	0.818	1.222
78	6800.	6513.	28	0.848	1.179
79	8240.	6430.	29	0.879	1.138
80	6710.	5777.	30	0.909	1.100
81	7280.	5692.	31	0.939	1.065
82	9288.	5239.	32	0.970	1.031

YUKON RIVER AT EAGLE ALASKA

SAMPLE STATISTICS
MEAN = 8629. S.D. = 2518.7 C.S. = 1.2644 C.K. = 4.5070
SAMPLE STATISTICS (LOGS)
MEAN = 9.0265 S.D. = 0.2667 C.S. = 0.6734 C.K. = 3.4235
SAMPLE MIN = 5239. SAMPLE MAX = 15400. N = 32
PARAMETERS FOR GUMBEL I A = 0.000575 U = 7551.

PARAMETERS FOR LOGNORMAL M = 9.0265 S = 0.2667
PARAMETERS FOR THREE PARAMETER LOG NORMAL BY MOMENTS A = 0.2334E 04 M = 8.6733 S = 0.3853
STATISTICS OF LOG(X-A)
MEAN = 8.6794 S.D. = 0.3669 C.S. = 0.4311 C.K. = 3.2541
PARAMETERS FOR LOG PEARSON III BY MOMENTS A = 0.0898 B =0.8821E 01 LOG(M) = 8.2343 M = 0.3768E 04
PARAMETERS FOR LOG PEARSON III BY MAXIMUM LIKELIHOOD A = 0.1033 B =0.6543E 01 LOG(M) = 8.3509 M = 0.4234E
DISTRIBUTION STATISTICS MEAN = 9.0265 S.D. = 0.2641 C.S. = 0.7819

	GUMBEL I		LOGNORMAL		THREE PARAMETER LOGNORMAL		LOG PEARSON III MAX LIKELIHOOD		LOG PEARSON III MOMENTS	
RETURN PERIOD	FLOOD ESTIMATE	ST. ERROR PERCENT	FLOOD ESTIMATE	ST. ERROR PERCENT	FLOOD ESTIMATE	ST. ERROR PERCENT	FLOOD ESTIMATE	ST. ERROR PERCENT	FLOOD ESTIMATE	ST. ERROR PERCENT
1.005	4650.		4670.		4870.		5340.		5220.	
1.050	5610.		5370.		5430.		5750.		5680.	
1.250	6720.		6650.		6560.		6640.		6620.	
2.000	8190.		8320.		8180.		8040.		8080.	
5.000	10200.	5.46	10400.	5.49	10419.	6.79	10200.	0.01	10300.	12.50
10.000	11500.	6.20	11700.	6.36	11912.	8.15	11800.	0.01	11900.	16.30
20.000	12700.	6.84	12900.	7.23	13350.	9.28	13500.	0.01	13500.	21.80
50.000	14300.	7.54	14400.	8.32	15231.	10.50	15900.	0.01	15800.	30.70
100.000	15600.	7.99	15500.	9.08	16656.	11.20	17800.	0.01	17600.	38.30
200.000	16800.	8.38	16500.	9.80	18105.	11.90	19900.	0.00	19600.	46.30
500.000	18400.	8.83	17900.	10.70	20065.	12.60	23000.	0.00	22400.	57.50
2000.000	20800.	9.38	20000.	11.90	23108.	13.50	28300.	0.00	27300.	75.40
10000.000	23600.	9.89	22400.	13.30	26833.	14.40	35800.	0.00	33900.	97.20

SECTION 4

HYDRAULICS

4.1 RIVER PROFILES

Profiles for the Yukon, Stewart, Pelly and Teslin Rivers are shown on Figures 4, 5 and 6. These profiles were developed from the 1:50,000 topographic maps. Profile distances were measured along the centreline of the main channel. Elevation data consisted of the 100 foot contour intersections with the main channel, benchmarks on the river banks and the geodetic reference for WSC gauging stations. Profile plotting points were taken as:

- The contour elevation
- The benchmark elevation, less five metres
- The WSC gauge height corresponding to the mean annual flow

The Yukon, Stewart, Pelly and Teslin Rivers have relatively uniform gradients throughout the reaches included in the study area. A summary of overall river gradients is as follows;

River Gradients - Yukon River Basin

River/Reach	Distance (km)	Elevation Diff. (m)	Gradient (m/km)
Yukon/Whitehorse - Eagle	830	373	0.4
Teslin Lake - Yukon River	175	88	0.5
Pelly/Ross River - Yukon River	407	262	0.6
Stewart/Mayo - Yukon River	250	131	0.5

4.2 CHANNEL CROSS-SECTIONS

Cross-sections of the river channel at the various WSC gauging locations were developed from WSC metering notes. These sections were referenced to geodetic datum, where available, otherwise the gauge height reference was used. These cross-sections and the corresponding stage-discharge curves for each section are shown on Figures 7, 8, 9, 10, 11 and 12. It should be noted that the metering section is not always exactly at the gauge location. Basic cross-section information and the gauge datum reference are summarized on Table 4-1.

4.3 FLOOD STAGES

The flows corresponding to the Mean Annual Flood (MAF) and the 1:100 year flood at each of the WSC stations were determined from the regional analysis curves shown on Figure 3. In the

case of the stations at Whitehorse and above Frank Creek, the flow values from the frequency analysis of data for each station (Table 3-1) were used. The resulting flood flow values are shown on Figure 2.

Values for the MAF and the 1:100 year flood were plotted on the cross-section/stage discharge plots for each gauging station and the corresponding flood stages determined. This information is summarized on Table 4-2.

TABLE 4-1

WSC CROSS-SECTION DATA - YUKON RIVER BASIN

River - Location		Date	Q (m^3/s)	A (m^2)	v (m/s)	Gauge Zero Elev. (m)
Yukon	- Whitehorse	Aug 31/71	606	311	1.95	623.156
	- Frank Cr.	Aug 22/80	666	334	1.99	-
	- Carmacks	Jun 18/79	1,691	764	2.21	515.688
	- White River	Jun 14/79	3,598	1,598	2.25	-
	- Dawson	Jun 12/79	6,884	2,927	2.35	311.826
	- Eagle	Jun 19/67	7,082	3,215	2.20	-
Stewart	- Mouth	Jun 15/79	1,722	910	1.89	-
	- Crossing	Jun 3/72	2,705	1,236	2.19	-
	- Mayo	Jun 10/77	1,700	1,078	1.58	479.478
Pelly	- Crossing	Jun 6/79	2,091	911	2.30	458.288
	- Vangorda	Jun 5/79	1,221	727	1.68	633.265
	- Ross River	Jun 5/72	1,059	683	1.55	689.679
Ross	- Ross River	Jun 5/79	433	184	2.35	694.597
Teslin	- Teslin	Jun 22/77	1,215	1,013	1.20	675.537
	- Whitehorse	Jun 20/73	1,096	642	1.71	600.707
Klondike	- Bonanza	May 31/77	368	138	2.67	319.327
Big Salmon	- Carmacks	Jun 6/78	234	124	1.89	-

TABLE 4-2

FLOOD FLOWS AND STAGES - YUKON RIVER BASIN

RIVER	LOCATION	FLOOD FLOW (m^3/s) MAF	FLOOD FLOW (m^3/s) 1:100 YEAR	FLOOD STAGE (m) MAF	FLOOD STAGE (m) 1:100 YEAR	STAGE DIFFERENCE MAF/1:100
Yukon	Whitehorse	520	680	632.6	633.1	0.5
	Frank Creek	690	840	5.5	6.0	0.5
	Carmacks	2,160	4,650	520.7	523.6	2.9
	White River	4,090	8,790	3.6	5.3	1.7
	Stewart River	7,010	15,100	5.2	7.6	2.4
	Dawson	7,400	15,900	316.1	320.0	3.9
	Eagle	8,280	17,800	7.0	11.0	4.0
Stewart	Mayo	1,600	3,680	486.1	489.0	2.9
	Stewart Crossing	1,770	4,060	5.7	8.5	2.8
	Mouth	2,530	5,810	29.0	30.7	1.7
Pelly	Ross River	960	2,210	692.7	694.2	1.5
	Vangorda	1,140	2,630	640.3	642.6	2.3
	Pelly Crossing	2,430	5,590	463.1	465.7	2.6
Ross	Ross River	395	910	697.7	698.8	1.1
Klondike	Bonanza Creek	425	980	321.8	322.8	1.0
Big Salmon	Carmacks	250	535	1.7	2.9	1.2
Teslin	Whitehorse	1,150	2,480	604.2	606.5	2.3
	Teslin	970	2,290	683.8	687.1	3.3

Note: Values for the MAF and 1:100 year flood are based on the regional flood frequency analysis, except for Whitehorse and Frank Creek on the Yukon River where the individual station analysis values from Table 3-1 have been used.

SECTION 5

FLOODING

5.1 CAUSES OF FLOODING

Floods in the Yukon River Basin result from snowmelt runoff, rainstorm events, a combination of rainfall on snowmelt, glacier melt and ice jams during the break-up period.

5.1.1 Spring Runoff

On the lower portion of the Yukon River (from the Teslin River confluence, downstream) and on the Teslin, Pelly and Stewart Rivers the peak flows during the spring runoff period result primarily from snowmelt. The effect of rainfall on snowmelt becomes more pronounced with decreasing basin size.

5.1.2 Rainstorm Events

The smaller watersheds can experience peak floods from summer rainstorm events which are greater than the peak flow from snowmelt runoff in a particular year. At higher elevations, rainfall events are more significant in producing peak flood flows on small tributaries. In the analysis of flooding in small drainage areas, the peak flows resulting from both snowmelt runoff and summer rainstorms should be determined.

5.1.3 Glacier Melt

Peak flows in the headwaters of the White River system that drain from the glaciers in the St. Elias Mountains are usually the result of runoff from glacier melt. Such peak flows generally occur in July and August. Flooding on streams in this area can also result from the sudden release of water ponded behind an ice dam formed by a glacier surging into, or across, a valley and temporarily closing off the watercourse. Such events are referred to as jökulhlaups, an Icelandic term for a glacier outburst flood.

5.1.4 Ice Jams

Increased water levels caused by ice jams affect only relatively short reaches of a river (as compared to the reach which may be subjected to high open water flow). Thus, while the extent of flood caused by ice jams may not be large, the real danger lies in the fact that ice jam formation is impossible to predict and the rise in water level behind the jam is rapid, occurring within a matter of hours or even minutes. There are three types of ice jam that can occur on rivers in the study area:

a) Jams caused by broken ice piling up on, and in front of, a solid ice sheet. Such jams are common where a tributary stream breaks up prior to the main stem of a river system or a lake and broken ice from the tributary piles up against the solid ice cover. This type of jam occurs during spring break-up and is referred to as a "floating" ice jam. The ice jams that occur on the Yukon River during spring break-up are typical of this type.

b) Jams caused by the accumulation of ice floes and broken ice at a point on the river where the downstream movement of the ice is temporarily impeded by some channel obstruction (narrow reach of river, sharp bend, shallow river section with ice sheet frozen to the bottom). The broken ice extends to the bottom of the channel and there may, or may not, be a solid ice cover downstream of the jam. This type of jam also occurs during spring break-up. It is referred to as a "grounded" ice jam. Typical examples are the ice jams on the Klondike River at Rock Creek and on other shallow streams.

c) Accumulation of slush ice and frazil ice at the leading (upstream) edge of a solid ice cover. These accumulations cause a restriction in channel capacity, with a resulting increase in upstream water levels. Such jams occur in late fall and early winter when the ice cover is starting to form on the river. Formation of this type of jam requires a section of river that is a slush ice or frazil ice "generator" (rapids, spillway, etc.,). This is termed an ice "dam". The flooding problems in the Marwell area of Whitehorse are the result of an ice dam.

5.2 SPRING BREAK-UP

Detailed accounts of the break-up of the Yukon River in 1982 and 1983 are given in the reports by T.D. Kent for the Yukon River Basin Study cited in Section 2.6. The breakup of the Yukon River in 1979, 1980 and 1981 is described in the report by Mel Orecklin which is also listed in Section 2.6. Based on these reports, the following general observations can be made regarding the spring break-up process:

- There is a general south to north progression of break-up on the Yukon River, although this progression is not consistent. The break-up process occurs in a series of reaches along the river; the upstream (southern) end of each reach having open water, followed by a section of broken ice and then a section of solid ice cover.

- During break-up, the smaller tributaries start to flow first and shore leads develop on the receiving watercourses.

- The general progression of break-up on the Yukon River, according to Kent, is as follows:

  1) Whitehorse to Lake Laberge and Lake Laberge to Carmacks (Rink Rapids) breaks up first. Ice cover on Lake Laberge remains for some time.

  2) Yukon River downstream of the Klondike River.

  3) Yukon River between White River and Klondike River.

  4) Yukon River between Carmacks (Rink Rapids) and Pelly River.

  5) Yukon River between Pelly River (Fort Selkirk) and White River.

- Break-up on the principal tributaries to the Yukon River appears to occur in the following order:

  1) Headwater tributaries upstream of Lake Laberge.

  2) White River

  3) Klondike River which generally breaks up a few days before the Yukon River at Dawson.

  4) Stewart River and the Pelly River

- Records of the timing of break-up on the Pelly River from 1956 to 1983 were obtained from the Bradley Brothers at Pelly Farm. In 20 out of 28 years the Pelly River broke up a few days ahead of the Yukon River at Dawson. In 1982 and 1983, the Pelly River break-up was one and three days, respectively, later than the Yukon River at Dawson.

5.2.1 Ice Jam Locations

Ice jams are known to form at many locations along the lower reach of the Yukon River, below Lake Laberge. The Klondike River is also frequently subject to ice jams. Occurrence of ice jams on the Stewart, Pelly and Teslin Rivers appears to be much less frequent. Historic information on ice jams that occur during spring break-up is not sufficiently detailed to allow a distinction to be made between floating ice jams and grounded ice jams at the various locations. Ice jams that occur at the mouth of the Klondike River prior to the break-up of the Yukon River are probably of the floating type. Farther up the Klondike River (at Rock Creek, for example) ice jams are likely to be the grounded kind.

The Marwell area at the north end of the City of Whitehorse frequently experiences flooding during the late fall and early winter as a result of the formation of an ice dam on the Yukon River. The only other areas reported to be subject to flooding as a result of the formation of an ice dam are in the vicinity of Yukon Crossing, downstream of Rink Rapids on the Yukon River and at Carmacks.

The reported locations of ice jams (floating, grounded) are given on Table 5-1.

5.2.2 Floating Ice Jams

The phenomenon of ice jam formation and stability has been the subject of considerable research. However, because of the number of variables involved, the formation and behavior of the ice jams is difficult to predict or analyse. Study has also been hindered by the difficulty in obtaining actual measurements during ice jam events.

Research has concentrated on the analysis of the floating ice jam which allows for flow of water underneath and the application of basic hydraulics to the phenomenon. The grounded ice jam which constricts the flow completely is less predictable and, as a result, little is known about this type of jam.

If one assumes that the required combination of physical channel characteristics and ice conditions exist at a particular point on a river to cause a floating ice jam, the rsulting stage behind the jam for a given discharge may be estimated by means of the following equation.

$$Q = \frac{0.0408}{n_o} B^{0.5} Y^{2.16} \qquad (1)$$

Where: B is the channel width in metres
Y is the overall depth in metres
Q is the discharge in cubic metres per second
n_o (0.10) is the composite roughness composed of the channel roughness n_b (0.03) and the ice roughness n_i (0.15) related by the following Sabaneev equation:

$$n_o = \left[\frac{n_b^{3/2} + n_i^{3/2}}{2}\right]^{2/3} \qquad (2)$$

Equation (1) applies only to floating ice jams. It is based on the classical theory of unconsolidated ice jams which states that an ice jam becomes unstable for a ratio of ice jam thickness to water depth of 0.41. The results obtained from this equation have correlated well with actual measurements

taken on rivers in northern Alberta. The condition for stability of these ice jams is an angle of internal friction of 21 degrees for the ice pack. For a discussion on the development of these equations and values of n_b and n_i, refer to "On River Ice Hydraulics" by Professor B. Michel, Laval University, presented as a discussion on Session B in the Proceedings of Workshop on Hydraulic Resistance of River Ice, NWRI, September 23-24, 1980.

Equation (1) can be used to compute the maximum water level at which a floating ice jam remains stable. The series of curves on Figure 13 have been developed to show the relationship among the following variables:

- River discharge - m^3/s
- River width - m
- River depth upstream of ice jam - m

The curves shown on Figure 13 can be used to determine the depth of water that could occur behind an ice jam at a particular point on a river, provided an estimate can be made of the river flow at the time of break-up. Alternatively, the break-up flow that will result in a given stage (say the 1:100 year open water stage) behind an ice jam can be determined. The height of the ice jam can be estimated by determining the difference in open water stage between that for the 1:100 year flow and the flow that would produce the same stage, but with an ice jam.

For example, the 1:100 year flood flow on the Yukon River at Dawson is 15,900 cubic metres per second. At this flow the river depth is 13 metres and the river width is about 350 metres. From Figure 13, a river flow of 2,000 cubic metres per second combined with a floating ice jam in the immediate vicinity of Dawson would produce the same river stage of 13 metres. Using the rating curve at Dawson, shown on Figure 7, the difference in stage between 15,900 and 2,000 cubic metres per second is 7.0 metres. This is the height of the ice jam that could result with a spring break-up flow of 2,000 cubic metres per second.

Although the above equation is not universally accepted, it can provide useful estimates. The main purpose of presenting these estimates here is to demonstrate the severity of ice jam flood stages from relatively low flows, as compared to open water flood.

5.3 HISTORIC FLOOD EVENTS

The archives research conducted as part of this study did not reveal any historic flood events that appeared to be more severe than those that have occurred during the period of

records for the WSC gauging stations. Historic flood events that have occurred in the Yukon River basin during the period of WSC gauging station records are:

Yukon River

The highest open water flood flows at Eagle, Dawson and Stewart River occurred in 1964. Farther upstream, above the White River and at Carmacks, the flood flows of record occurred in 1962.

Ice jams on the Yukon River in 1944, 1966 and 1979 caused slightly higher (1.0 to 1.2 metres) water levels at Dawson than did the 1964 open water flow.

Stewart River

The peak flood flows at the three WSC stations on the Stewart River occurred in 1964.

Pelly River

At Pelly Crossing, the peak flow occurred in 1957; however, the 1964 flow was only four percent lower. The highest flow at Ross River was in 1964.

Teslin River

Peak flood flows on the Teslin River were in 1962; the second highest flows (seven percent lower) were in 1964.

5.4 FLOODING OF SETTLED AREAS

The flooding of settled areas has been documented in previous reports. The statements regarding flood levels that have been experienced in the past are based on the data contained in these reports and information gained from local residents during the reconnaissance survey carried out for this study. The 1:100 year open water flood levels stated have been derived from the hydrologic and hydraulic anlayses presented in Sections 3 and 4 of this report. In the design of flood protection works, appropriate freeboard allowances must be made for ice push-up (and wave up-rush in the case of lakes).

5.4.1 Dawson City

Dawson City is built on a floodplain of the Yukon River and historically has been subject to flooding by both the Klondike and Yukon Rivers. High river stages at Dawson have been caused by both floating ice jams and by open water flow. A summary of historic high water levels and the 1:100 year stage at Dawson is as follows:

High Water Levels at Dawson City

Year/Event	Elevation	Cause
1925	319.9 m	
1944	320.8 m	Ice jam on Yukon River
1964	319.6 m	Open water flow
1966	320.6 m	Ice jam on Klondike River
1979	320.7 m	Ice jam on Yukon River
1:100 year	320.0 m	Open water flow

5.4.2 Rock Creek

The community of Rock Creek on the Klondike River and sections of the Klondike Highway along the river have been flooded due to the backwater effects of grounded ice jams on the Klondike River. Such ice jams are probably typical occurrences of what happens on similar shallow rivers and streams. Recent flooding in the community of Rock Creek occurred in 1979, 1981 and 1982. In 1983, there was an ice jam at the Klondike Highway Bridge over Flat Creek, a tributary of the Klondike River. Many of the houses in Rock Creek are located on ground that is only about two metres above the summer water level in the Klondike River (flow of 115 cubic metres per second in August, 1983).

5.4.3 Mayo Area

The Town of Mayo is located on the right bank of the Stewart River, just upstream of the Mayo River confluence. In the past, flooding of the town has been caused by ice jams on the Mayo River and by high open water stages on the Stewart River. Break-up of the Mayo River occurs prior to that of the Stewart River and the broken ice from the Mayo River piles up on the solid ice sheet on the Stewart River.

Some degree of flood protection for Mayo is provided by dykes along the Mayo and Stewart Rivers. The native community on the upstream side of town is slightly lower lying and has no protection. The current practice of the Northern Canada Power Commission in operating their hydroelectric plant on the Mayo River is to increase the water release sufficiently to cut a channel in the ice just prior to breakup. This procedure has been successful in preventing Mayo River ice jams in recent years. Flood levels at Mayo are summarized in the following tabulation:

High Water Levels At Mayo

Year/Event	Elevation	Remarks
1936	-	1.2 m depth in town
1964	489.6 m	Open Water
1983	489.0 m	Open Water
1:100 year	489.0 m	Open Water

In 1983 the high water was reported to be less than one metre below the top of the dyke along the Stewart River.

5.4.4 Pelly Crossing

There has been no reported flooding of the community at Pelly Crossing. There was, however, a report that during one spring runoff period the water from the Pelly River had overflowed the left bank of the river at a point just south of the village and crossed a low section of the highway.

The 1:100 year open water stage at Pelly Crossing is estimated to be elevation 465.7 metres. During the reconnaissance of August, 1983 the left bank of the river at the village was estimated to be six metres above the present water level, or at about elevation 467 metres.

5.4.5 Carmacks

One person interviewed reported flooding of Carmacks in 1910, in the late 1920's and in 1958. It was also reported that ice jams did not occur in the area, although there would be an ice dam form if the fall freeze-up period was mild. The year 1958 had the lowest peak flow of record. Thus, if the town did flood at that time, it must have been due to an ice jam.

The 1:100 year open water stage at Carmacks is elevation 523.6 metres. The street along the left bank of the river was measured to be 4.2 metres above the river level on August 30, 1983. The top of the street is therefore at elevation 523.5 metres, approximately. The Indian community, on the right bank, appeared to be at a slightly lower elevation.

5.4.6 Ross River

Some low-lying areas of Ross River have been subjected to flooding in the past. The most severe floods occurred in 1964 and 1972. These were both open water spring runoff events. The 1972 flood reached a level that was surveyed to be about 1.9 metres above the August 27, 1983 level, or approximately elevation 693.2 metres. In 1976 there was an ice jam on the Pelly River, downstream of the community and the ice nearly reached the Catholic church residence. This was slightly lower than the 1972 flood.

The WSC station rating curve shows elevation 693.6 as the level of the 1972 flood. The 1964 flood was 0.4 metres higher. The 1:100 year open water stage is elevation 694.2 metres.

5.4.7 Whitehorse

Flooding in Whitehorse appears to be limited to the Marwell area where a freeze-up ice dam causes water to frequently flood

a low-lying area. City of Whitehorse officials are well aware of this problem and the area is zoned to preclude any future residential construction.

5.4.8 Teslin

The Town of Teslin on the shore of Teslin Lake has experienced some flooding of low-lying areas. Teslin Lake water level records are rather sporadic. The recorded high level is elevation 685.6 metres on June 16, 1961. The levels for the WSC gauge on the Teslin River near Teslin (Johnsons Crossing) are very close to the Teslin Lake level. The highest flood flow on record (1962) resulted in a water level at elevation 686.1 metres. The 1:100 year open water flood level is elevation 687.1 metres.

5.5 OTHER FLOOD-PRONE AREAS

The identification of flood-prone areas along the principal tributaries in the Yukon River Basin, outside the settled areas, was carried out by an inspection of the 1:50,000 topographic maps, stereoscopic viewing of aerial photography and visual estimation of bank heights at selected locations during the field reconnaissance. The difference in level between the mean annual flood and the 1:100 year flood on the various rivers is relatively small (4.0 metres, maximum). Given the accuracy with which differences in ground levels can be estimated with the data base, it is difficult to define the areas that would be inundated by the 1:100 year flood. The comments provided in the following paragraphs of this Section 5.5 must therefore be considered as somewhat subjective. Also, these comments do not include the potential effects of ice jams. In reading the following descriptions, there are definitions of two terms that should be kept in mind.

Floodplain	Areas of the valley bottom that are no more than a few metres above river level and are probably inundated by the 1:100 year flood. River islands would always be considered as being in the floodplain.
Valley Bottom	Designates the generally flat part of the river valley floor. Such areas could rise 10 to 20 metres above river level. Width definitions include the width of the river.

5.5.1 Yukon River

The reach of the Yukon River investigated extends from Whitehorse to the Yukon Territory - Alaska border. Comments regarding flooding are as follows:

Whitehorse to Upper Laberge

River generally flows between high banks on both sides. There are some minor low-lying areas at the mouth of the Takhini River and at the entrance into Lake Laberge, although it is unlikely there would be any significant areas flooded under the 1:100 year event.

Lake Laberge

Normal lake level fluctuation appears to be about two metres. Area subject to flooding is very small.

Lower Laberge to Teslin River

This section of river, known as The Thirty Mile, also generally flows between steep sided banks. There is very little area in the floodplain. With the exception of the reach in the vicinity of U.S. Bend, the course of the river is fairly straight.

Teslin River to Big Salmon

River flows in valley which normally has a bottom width of 0.5 kilometres, with occasional areas being up to 1.5 kilometres in width. Small floodplain areas at the mouth of the Big Salmon River and about five kilometres downstream, at the mouth of Walsh Creek.

Big Salmon to Little Salmon

Valley bottom commonly one kilometre wide. Evidence of a few cutoff channels and a limited amount of land, generally on the inside of bends, in the floodplain.

Little Salmon to Carmacks

Width of valley bottom is typically in the order of two kilometres, except at Eagle's Nest Bluff. Limited amount of land in the floodplain. This typical section extends to Tantalus Butte, about 10 kilometres downstream of Carmacks.

Carmacks to Rink Rapids

Valley bottom generally about 0.5 kilometres wide. Very little land in the floodplain. Five Finger Rapids is located in this section.

Rink Rapids to Fort Selkirk

Width of the valley bottom is commonly two kilometres. Channel contains numerous islands and sand bars. Limited amount of land in the floodplain. At many points the channel is 500 to 1,000 metres wide and there are many islands in the channel.

Fort Selkirk to Stewart River

Three kilometres downstream of Fort Selkirk, the valley bottom narrows to less than one kilometre. From this point to the White River the river flows through rugged country. There is little land in the floodplain other than at the mouths of the more significant tributaries such as the Selwyn River, Coffee Creek and Independence Creek (opposite Kirkman Creek). There is a floodplain area on the left bank of the Yukon River, both upstream and downstream of the White River confluence. The floodplain is about 1.5 kilometres wide by 6 kilometres long. Downstream, the floodplain is 1.0 kilometres in width and about 10 kilometres long.

Stewart River to Dawson

Downstream of the Stewart River there are numerous locations where there are smaller side channels to the main river. The intervening land is probably floodplain. In the first 25 kilometres, the width of river and floodplain is two to three kilometres. Thereafter the river flows in a channel with well defined banks of some appreciable height down to Dawson. The channel contains numerous islands. Floodplain in this lower reach (other than islands) is limited.

Dawson to Alaska Border

In this reach the river is generally well confined between steep banks. There are islands near Moosehide, Fort Reliance and close to the Alaska border. Very little floodplain land.

5.5.2 Teslin River

The entire length of the Teslin River, from Teslin Lake (Johnsons Crossing) to the Yukon River confluence was included in this study.

There is a small floodplain area on the right bank of the river, about eight kilometres downstream from Johnsons Crossing. The river flows in a fairly direct line in a northwesterly direction and is well confined between steep banks down to the Swift River. At this point its course becomes slightly more convoluted and the valley bottom widens, at times, to one kilometre. There is little land in the floodplain.

5.5.3 Pelly River

The following discussion applies to that section of the Pelly River between Ross River and its confluence with the Yukon River.

Ross River to MacMillan River

In this reach, the Pelly River meanders from one side to the other of a broad U-shaped valley, that is one to two kilometres wide. There are numerous old abandoned sections of channel, active side channels and oxbow cutoffs. The main channel is still in the process of active formation. Much of the valley bottom could be considered floodplain.

MacMillan River to Pelly Crossing

The river is well confined to the channel in this reach and there is very little floodplain land.

Pelly Crossing to Yukon River

Except for a 12 kilometre reach in the vicinity of Bradens Canyon, the river flows in a broad valley. From Pelly Crossing to Bradens Canyon this valley is about two kilometres wide and has a fairly extensive floodplain. Downstream of the narrow Badens Canyon sector, the valley bottom is one to two kilometres wide, but with little floodplain. There is little evidence of channel shifting throughout the reach from Pelly Crossing to the Yukon River.

5.5.4 Stewart River

The reach of the Stewart River from Mayo to the Yukon River was included in the study area.

Upstream of Mayo

Upstream of Mayo the river meanders across a three to four kilometre wide valley. A considerable amount of this land could be considered floodplain.

Mayo to Sixteen Mile

The river flows within steep banks and there is no floodplain.

Sixteen Mile to Stewart Crossing

Valley bottom width is two to four kilometres with numerous cutoff oxbows and side channels. There is an extensive floodplain within the valley bottom.

Stewart Crossing to Steamboat Bar

River flows in a two to three kilometre wide valley. Fairly extensive floodplain from the McQuesten River, upstream for a distance of about 20 kilometres.

Steamboat Bar to Yukon River

About five kilometres downstream of Steamboat Bar the valley narrows considerably for a distance of about 15 kilometres and there is very little floodplain. Thereafter the valley bottom has a width of two to three kilometres down to a point upstream of Scroggie Creek. There is a limited amount of land in the floodplain. From Scroggie Creek, downstream for 25 kilometres the river is contained between steep banks. The last 15 kilometre length to the Yukon River has about a two kilometre valley bottom. There is extensive floodplain land, especially at the mouth.

5.5.5 Klondike River

The lower reach of the Klondike River, from Flat Creek to the Yukon River, has a wide, shallow channel with numerous oxbow cutoffs and small side channels. Valley bottom width is one to two kilometres. A small amount of land is in the floodplain.

5.5.6 White River Headwaters

The headwaters of the White River system lie in the glaciers of the St. Elias Mountains. Surging of glaciers has been known to close off small headwater streams and form lakes. These glacier "dams" can subsequently let go and cause local flash floods. The releases from these lakes formed by glacier dams result in the dominant floods on the Donjek River and probably on the White, Duke and Alsek Rivers. The effects of these flash floods are likely experienced for some considerable distance down the White River.

5.6 FLOOD FORECASTING

Water based transport, during the summer, played an important part in the development of the Yukon Territory during the first half of the 20th century. As a result, nearly all communities are located on areas of reasonably level land adjacent to the major rivers and lakes. Unfortunately, most of these reasonably level areas are floodplains and the underlying soil is often pervious and the groundwater table is a reflection of adjacent river water levels.

Knowing that a particular portion of a settlement or development is located on a floodplain and, therefore, subject to periodic flooding, the long term objective should be one of the following:

- Abandon the affeced area and move to higher ground, or
- Provide some reasonable degree of flood protection.

In the short term, some means of forecasting the advent of a flood can be used to provide advance warning to potentially affected persons to prepare for the consequences of a particular event.

5.6.1 Open Water Events

Gradients on the major tributaries of the Yukon River system are such that open water flood stages travel at the rate of about 200 kilometres per day. Therefore, upstream monitoring of water levels either provides very little advance warning, or the station is located so far upstream that significant intervening inflows will not be gauged.

A watershed model that simulates the snowmelt process and the resulting runoff, coupled with a water level recorder (and stage discharge curve) near the point of interest on the river can be used to provide longer warning times for peak flows and levels.

Such a model has been developed for the Stewart and Pelly Rivers to estimate the floods that will occur at Mayo and Ross River. It has been used by Indian and Northern Affairs Canada for the past few years, reportedly with a reasonable degree of accuracy. The development, calibration and use of this model is discussed in the report "Spring Flood Forecasting for Mayo and Ross River" by Jac P. Verschuren and D. Crawford. The model is based on the degree-day method of simulating snowmelt. Model input consists of recorded daily maximum temperatures and daily precipitation from the start of the snowmelt process, total monthly precipitation during the previous winter, mean daily discharge at the outlet from the watershed and the area elevation relationship for the watershed. The model can be used with forecasts of maximum daily temperature and daily precipitation to estimate future flows. The period of advance warning depends on the lead time of the meteorological forecasts. If extensive areas of open ground exist in the watershed at forecast time or if there is a heavy rainfall prior to the occurrence of peak discharge, the model does not produce reliable estimates.

There are presently no settled areas, other than Mayo and Ross River, where this watershed model, or any other model, could be used to advantage.

5.6.2 Ice Jam Events

Ice jam formation is impossible to predict with any degree of accuracy. Once an ice jam starts to form, the headpond behind the jam rises quickly and the advance warning time derived from any water level system would be a matter of only a few hours. Therefore, in areas along the rivers known to be affected by ice jams, about the only solution is a watchful eye during

break-up. This could be supplemented by aerial reconnaissance to identify ice jam formation downstream and upstream of the area of concern.

5.7 FLOOD DAMAGE REDUCTION

Once a flooding problem in a particular developed area has been experienced, public funds are often expended to repair the damage caused to both public and private property. Aside from the financial losses that occur as a result of a flood, there are other consequences such as human anguish, hardship and threat of possible loss of life.

If people had known or understood the severity of the potential problems when settling on the flood-prone areas, they would probably have chosen another location. Today, there are two problems relating to flood-prone areas that should be addressed:

- Provision of reasonable level of flood protection for existing developments on floodplains.

- Establishment of the means by which future development is controlled so that it cannot take place on a floodplain.

5.7.1 Dyking Protection

To date, flood protection in the Yukon Basin has been limited to dyking along the river banks to impede the encroachment of rising flood waters on particular communities such as Dawson, Mayo and Ross River. Dyking was often done, or added to, at the time of rising river stages. Particularly at Dawson, the consequences of dyke overtopping are well understood.

Dyking practice could certainly be improved. Dyke construction for flood protection does not seem to have received the attention it deserves. Very little, if any forward planning has been used and there are no "standards" set as to the level of protection to be provided. In Dawson, there is no uniform elevation for the top of the dyke. In Mayo, the dykes are not maintained permanently and sections are often removed after a particular emergency has passed.

5.7.2 Flood Flow Reduction

Flood flow reduction provides a more secure means of flood protection than does dyking since there is still some protection afforded when the design flow or stage is exceeded in a flow regulation scheme. In connection with previous investigations to define feasible hydroelectric power development in the Yukon River Basin, a number of river storage and diversion schemes have been identified. Some of these potential

developments could be operated in such a manner as to achieve a significant reduction in flood flows. In order to provide an indication of the effect of regulation or diversion schemes on downstream flood flows, a number of alternatives were considered.

Control Locations

The Inland Waters Directorate (IWD) provided the following control locations and degrees of reduction in the 1:100 year open water flood outflows from the controls as examples to demonstrate the effects of such controls on downstream flood levels. These examples do not reflect the results of studies of proposed developments at these control locations, but were provided to give an idea of the magnitude of downstream effects at various points along the rivers and to serve as guidelines from which various peak flow reductions could be anlaysed in subsequent studies. The following flood flow reduction examples were analysed:

Yukon River	Reduction of the flow on the Yukon River at Carmacks by 50 percent, along with a 50 percent reduction in the flow on the Pelly River at Pelly Crossing.
Teslin River	Reduction of 50 percent in the outflow from Teslin Lake.
Stewart River	Reduction in the flow on the Stewart River at Mayo by 25 percent.

Downstream Effects

On the Yukon River the flows during the spring freshet period in 1962, 1964 and 1975 were input to the SIMPAK flood routing model (by IWD) and the effects of the flood flow reductions at the control locations on the resulting flows at downstream locations were simulated. The percentage reduction in peak flows at downstream locations resulting from the controls were determined. These percentage reductions were then applied to the 1:100 year un-regulated flood flows and the corresponding reductions in flood stage were determined. The downstream effects of controls on the Yukon River at Carmacks and on the Pelly River at Pelly Crossing are summarized in the following tabulation:

Yukon River 1:100 Year Flood Reduction

River - Location	Percent Reduction	1:100 Year Flood Flow (m^3/s) Natural	Regulated	Reduction in Stage (m)
Pelly - Pelly Crossing	50	5,590	2,800	2.3
Yukon - Carmacks	50	4,650	2,330	2.7
Yukon - White River	46	8,790	4,750	1.4
Yukon - Stewart River	23	15,100	11,600	1.0
Yukon - Dawson	22	15,900	12,400	1.6
Yukon - Eagle	15	17,800	15,100	0.9

On the Teslin River it was assumed that the peak flood outflow from Teslin Lake was reduced to 50 percent of the unregulated 1:100 year flow. The downstream flood inflow is unregulated and the regulated peak outflow from the lake and the unregulated peak downstream drainage were assumed to be coincident. The effect of this flood flow regulation is summarized in the following table. The effect of Teslin River regulation on flood flows in the Yukon River has not been assessed.

Teslin River 1:100 Year Flood Reduction

River - Location	Percent Reduction	1:100 Year Flood Flow (m^3/s) Natural	Regulated	Reduction in Stage (m)
Teslin - Johnsons Cros.	50	2,290	1,150	2.7
Teslin - Near Whitehorse	46	2,480	1,340	2.0

The 1:100 year flood flow on the Stewart River at Mayo was considered to be reduced by 25 percent. Downstream inflows from intervening drainage areas were assumed to be unregulated and their flood peaks coincident with the regulated peak flow at Mayo. The effect of Stewart River regulation on the Yukon River flood flows was not analysed. The results of Stewart River regulations are:

Stewart River 1:100 Year Flood Reduction

River - Location	Percent Reduction	1:100 Year Flood Flow (m^3/s) Natural	Regulated	Reduction in Stage (m)
Stewart - Mayo	25	3,680	2,760	1.2
Stewart - Stewart Cros.	23	4,060	3,140	1.1
Stewart - The Mouth	16	5,810	4,890	0.3

5.7.3 Benefits of Flood Flow Reduction

The flood stage and flow reduction benefits resulting from regulation facilities would be, naturally, most significant at a location immediately downstream of the point of control. The

reductions in stage at various locations along the river systems are shown in the tabulations presented in Section 5.7.2. Because of the lack of detailed topographic information, such as mapping with 0.5 or 1.0 metre contour intervals, the significance of these stage reductions in terms of the decrease in area flooded along the river systems is rather obscure. The following specific comments can, however, be made:

- A 50 percent reduction in the flood flow at Carmacks would significantly reduce the 1:100 year open water stage at Carmacks and probably eliminate any possible flood damage from the 1:100 year unregulated flow. Such flood damage, however, would be minor and thus the value of benefits is low.

- A 50 percent reduction in the flood flow on the Pelly River at Pelly Crossing would prevent flooding at Pelly Crossing in the 1:100 year event. Here again, the benefits are considered minimal since there would be little, if any, flooding of the community under the 1:100 year unregulated flow.

- The regulation tested for the Stewart River is estimated to reduce the 1:100 year stage at Mayo by 1.2 metres. This is probably enough to eliminate the need for protection by a dyke along the Stewart River. The potential problem of flooding due to an ice jam on the Mayo River would still remain.

- The reduction in the 1:100 year flood stage on the Yukon River at Dawson is not sufficient to eliminate the need for a dyke. Also, flow regulation does not solve the problem of flooding from the Klondike River caused by an ice jam at the Yukon River confluence. Likewise, the effect of flow regulation in reducing the possibility of ice jam formation downstream of Dawson is not known.

5.7.4 Development Strategies

Development of lands adjacent to rivers and lakes should recognize the inherent dangers of encroachment on the floodplain. Control of development in flood-prone areas requires the establishment of effective land use planning regulations and the means of physically defining the boundaries of the floodplain.

Land Use Planning

The establishment of land use planning guidelines and regulations is the first step in controlling development in flood-prone areas. Firstly, there should be a recognition by all levels of government (municipal, territorial and federal) that development in floodplains should be restricted.

Secondly, the regulatory means must be put in place whereby proponents for a certain development have to seek approval and be granted some form of "permit" before proceeding. Some of the basic factors to be included in land use planning regulations dealing with flood-prone areas are:

a) The "level of protection" to be adopted i.e. the 1:100 year or the 1:200 year event.

b) The designation of a "floodway" as being the main river channel plus that part of the floodplain which must remain free of any obstructions or encroachments in order to carry the design flood. Developments such as a park or recreation field could be permitted inside the floodway, provided that the owners are made aware of the consequences of what could be frequent flooding.

c) Definition of the types of development that can take place in the floodplain area "outside" the floodway. This could include specification of minimum floor levels for buildings and the special erosion protection and seepage control features required.

Present land use planning policies in the Yukon Territory, in so far as flood-prone areas are concerned, consist of:

- With regard to federal lands, a development plan for a lease must be submitted. If there is an awareness of flooding, a lease will not be issued. If a lease is issued, then buildings must be 180 metres back from the high water mark (where known) or otherwise, from the river level.

- There appears to be no established policy for Yukon Territorial Government lands or lands in communities. Land is leased or sold on a "buyer beware" policy. The one known exception is in the City of Whitehorse where zoning restrictions control the type of development now possible in the Marwell area.

The Federal and Territorial governments have yet to conclude an agreement for a cost shared Flood Damage Reduction Program. Without such a program, or a similar undertaking by the Yukon Territorial Government, the rational and controlled development of floodplain lands is difficult. It is impossible to make wise investment decisions relative to land adjacent to rivers when the floodplain has not been defined.

Preliminary Floodplain Definition

The hydrology and hydraulic information on the principal tributaries of the Yukon River Basin contained in Sections 3 and 4 of this report can be used to provide a preliminary

assessment of the potential flood risk at a particular point in question. When assessing the flood risk in this manner, due attention should be paid to the relative "accuracy" of the variables. The various steps involved in the preliminary assessment of flood risk are:

a) Determine the drainage area of the river at the point of interest.

b) Identify in which region the river is located and determine the 1:100 year (or other) flood.

c) Establish a stage-discharge rating curve for the river at the point of interest by one of the following means:

- Streamflow and stage measurements over a range of flows.

- Stage measurements over a range of flows and flow determination by correlation with upstream and downstream WSC stations.

- Hydraulic computations using the river cross-section, channel roughness and slope.

d) Develop a river cross-section at the point of interest and extend the stage-discharge curve to include the design flood flow.

e) Determine the design flood stage from the stage-discharge curve and compare this level to that of the land in the adjacent area considered for development.

Floodplain Mapping

Floodplain mapping should be carried out for all areas where there is a risk of flooding existing or proposed developments. This involves the preparation of topographic maps with a contour interval of 0.5 or 1.0 metres, a hydrologic analysis of the watershed to determine the design flood flow and a study of the hydraulic characteristics of the river in the vicinity of the area of interest to define the design flood stage. Ice jam water stages require special analyses.

TABLE 5-1

ICE JAM LOCATIONS - YUKON RIVER BASIN

LOCATION	RELATIVE FREQUENCY OF OCCURRENCE		
	FREQUENT	OCCASIONAL	UNKNOWN
Klondike River			
- at the Mouth	X		
- at Highway Bridge	X		
- Bear Creek	X		
- Rock Creek	X		
- on Flat Creek (bridge)		X	
Stewart River			
- at the Mouth	X		
- Wildcat Slough			X
- Icechest Reef			X
- Chromartie Chute			X
- Jackman Chute			X
- Devils Elbow			X
- Mayo			X
- Mayo River at Mouth		X	
Pelly River			
- at the Mouth	X		
- Downstream Pelly Crossing			X
- Upstream Granite Canyon			X
- Downstream Ross River			X
Teslin River			
- Upstream Teslin Crossing			X
Yukon River			
- Miles Canyon			X
- Whitehorse	X		
- 8 km Downstream Whitehorse		X	
- Big Bend		X	
- Hootalinqua	X		
- Big Salmon	X		
- Little Salmon	X		
- Tantalus	X		
- Five Finger Rapids	X		
- Yukon Crossing	X		
- Hells Gate		X	
- Fort Selkirk	X		
- Coffee Creek	X		
- Kirkman Creek		X	
- Stewart River	X		
- Selwyn		X	
- Ogilvie	X		
- Indian River	X		
- Dawson	X		
- Moosehide		X	
- Fort Reliance		X	
- Cassiar Creek	X		
- Forty Mile		X	

APPENDIX A

YUKON RIVER BASIN

FLOOD RISK STUDY

FIELD RECONNAISSANCE NOTES

APPENDIX A

FIELD RECONNAISSANCE NOTES

A.1 INTRODUCTION

A reconnaissance of the study area was carried out by Mr. J.A. Knowles, P.Eng., accompanied by Mr. Dale Dawson, during the period August 25 to 31, 1983. The following is a summary of the areas visited:

August 25	Yukon River from Whitehorse to Upper Laberge, Lake Laberge.
August 26	Whitehorse to Johnsons Crossing, Teslin and return to Whitehorse.
August 27	Whitehorse to Carmacks, Faro, Ross River and return to Carmacks.
August 28	Carmacks to Five Fingers Rapids, Yukon Crossing, Minto, Pelly Crossing, Pelly Farm, Stewart Crossing and Dawson.
August 29	Dawson City area, including Klondike River and Rock Creek.
August 30	Dawson to Mayo, Stewart Crossing, Granite Canyon, Pelly Crossing, Carmacks and Whitehorse.
August 31	Whitehorse area.

Principal activities undertaken during the reconnaissance included:

- Measurement of river widths with a rangefinder and visual estimation of bank heights above present water level at accessible locations along the rivers. Oblique color photographs at each location.
- Reading of WSC gauges to obain estimates of river flow at the time of the reconnaissance.
- Examination of the river banks at accessible sites for evidence of high water marks and ice action.
- Interviews with local residents.

A.2 COMMENTS ON RIVER SECTIONS

Yukon River at Marwell Lift Station (Whitehorse)

- Width: 130 metres
- Water level about 2.0 metres below parking lot at lift station
- Photos 1-1 and 1-2

Yukon River at Robert Campbell Bridge (Whitehorse)

- Width: 85 metres
- Water level 2.90 metres below under side of bridge girder on right bank

Yukon River at Whitehorse Rapids

Data from the Northern Canada Power Commission indicates the following discharge at Whitehorse Rapids on August 24, 1983.

Turbines	3,950	
Spillway	11,480	
Total	15,430 cfs	or 440 m^3/s

Yukon River at Takhini River

- Yukon River width: 110 metres
- Low area on left bank, upstream of Takhini River confluence which is 2 to 4 metres from present water level
- No evidence of overbank flooding or ice action
- Photos 1-3, 1-4, 1-5 of Yukon River
- Photo 1-6 looking upstream on Takhini at highway bridge
- High silt bank on Yukon River opposite mouth of Takhini

Takhini River at Yukon River

- Width: 80 metres
- Ground on right bank, downstream of highway, is 3 to 4 metres above water level
- High silt banks upsteam of bridge

Yukon River Upstream of Lake Laberge (5 km)

- Width: 180 metres
- Left bank is 6 to 8 metres high and of fine sand and silt
- Right bank is low near river edges but rises about 50 metres from present shoreline
- About 1.0 km downstream, opposite an island, the sand banks are high on the left side of the river and the ground drops about 3 metres behind a levee style formation which is probably an aeolian deposit
- Photos 1-7, 1-8. Photo 1-9 taken farther downstream, looking back upstream

Yukon River at Upper Laberge

- Left bank upstream is silty sand and has height of 5 to 6 metres
- "Island" or sand bars shown on 1:50,000 map are well formed and distance from left bank to the island is 180 metres
- Appears to be a weather station on the island
- Downstream, the left bank drops somewhat and there is a wide area near the shore that is only 2 to 3 metres above the water level
- No evidence of ice action

Lake Laberge

- Some evidence that high water mark is about 1.0 metres above present lake level fairly often
- Other evidence such as scars on trees and occasional accumulations of driftwood to indicate maximum ice levels on shore to be about 2.0 metres above present water level
- WSC records show level variation to be about 2.0 metres, with peak in August-September

Summary - Yukon River, Whitehorse to Lake Laberge

1:100 Year Flow	= 680,	Gauge Height =	633.1
August 24/83 Flow	= 440,	Gauge Height =	632.4
		Difference =	0.7

The 1:100 year open water flow is less than one metre higher than present day water level

Yukon River, 6 km Downstream from Eagles Nest Bluff

- Width: 180 metres
- Left bank + 3 metres, but higher upstream
- Right bank + 6 metres
- Photo 3-4 upstream, 3-6 across, 3-5 downstream

Yukon River 8 km Upstream from Eastern End of Carmacks Airport

- Width: 210 metres
- Right bank + 5 metres
- Left Bank low (+ 2.5 metres)
- Photo 3-1 upstream, 3-2 across, 3-3 downstream

Yukon River 3 km upstream of Carmacks Bridge

- Width: 150 metres
- Robert Campbell Highway on right bank about 5.0 metres above water
- Left bank low (+ 3 metres)

Yukon River at Carmacks Bridge

- Section located at campground just downstream of bridge
- Width: 150 metres
- Right bank high + 9 metres
- Left bank low + 3 metres in campground area
- Photos 3-7 bridge, 3-8 across, 3-9 downstream
- Main road along the river in Carmacks is + 4.2 metres above present water level (Levelled at corner of Prospector Road)
- Photos 3-13 upstream, 3-14 across, 3-15 downstream
- WSC reported the gauge reading at Carmacks on September 20, 1983 to be 3.345 metres = Elevation 519.033 metres, corresponding to a flow of about 1,000 cubic metres per second

Yukon River Downstream of Abandoned Airfield at Carmacks

- Width: 155 metres
- Left bank + 5 metres
- Right bank + 2.5 metres
- Photos 3-10 upstream, 3-11 across, 3-12 downstream

Yukon River 2.5 km Below Five Finger Rapids

- Width: 210 metres
- Normal high water about 2.0 metres above present level
- Low area on left bank (+ 2.0 metres)
- Right bank is about 5.0 metres above water level. Downstream on right bank there is a high silt formation

Yukon River at Yukon Crossing

- Width: 220 metres
- Right bank 5 to 6 metres above water
- High, steep left bank downstream of abandoned settlement but low area upstream of buildings. Building site probably 2.5 to 3.0 metres above present water level
- Photos 1-22, 1-23 looking from right bank across to Yukon Crossing
- Banks high on both sides at point 3.5 km downstream of Yukon Crossing. Lowest is 10 metres high left bank. Photo 1-24 upstream, 1-25 downstream

Yukon River at Minto

- Width: 240 metres
- Both banks about 5.0 metres high
- Normal maximum water level 1.5 metres above present
- Photos 1-26 across, 1-27 downstream, 1-28 upstream

Yukon River 4.5 km Upstream from Klondike River

- Width: 500 metres
- Left bank + 4.5 metres above present water level
- Right bank high
- Photos 2-15 upstream, 2-16 downstream
- Normal high water + 2.0 metres
- Photos 2-17 Dawson, 2-18 Dawson, 2-22 Dawson Sign

Yukon River at Dawson

- At WSC Gauge, width is 350 metres
- Photos 2-11 across, 2-12 downstream
- Banks high on both sides
- At Canadian Imperial Bank of Commerce width is 240 metres
- Left bank high bedrock
- Photos 2-13 downstream, 2-14 upstream
- WSC gauge at Dawson was 2.532 metres on August 29, 1983. This corresponds to a water surface elevation of 314.358 metres, or a flow of about 4,200 cubic metres per second

Yukon River 3.5 km Downstream from Klondike River

- At site of old steamboats on left bank and about 1.0 km upstream from Moosehide
- Width: 240 metres
- Right bank high from Dawson to Moosehide
- Left bank low from Ferry to Steamboat and beyond (+ 4.5 metres)
- Photo 2-19 looking to right bank. Note the high water mark (+ 4.0 metres)
- Photos 2-20 left bank, 2-21 Steamboat Schwatka, Seattle No. 3 and Julia B.

Teslin River at Johnsons Crossing

- Width at bridge: 190 metres
- High silt bank on right side of river from bridge, upstream
- High water mark about 2.0 metres above present level
- Picnic site under bridge on left bank about 3.0 metres above water
- Photo 1-12 looking across the Teslin River from the picnic site
- Records kept by owners of the lodge at Johnsons Crossing indicated the following peak water levels for the gauge at the bridge.

Year	Gauge (ft)	Elevation (m)
1962	34.47	686.05
1964	33.55	685.77
1967	30.51	684.84

- The lodge owners recall 1963 as having the highest water, but have no record of the gauge height. They report this high level was caused by an earth slide on the Teslin River some 60 miles downstream from Johnsons Crossing

Teslin Lake at Teslin

- Photo 1-10 taken from west (left) shore looking at bridge and across to Teslin
- Photo 1-11 view of west shore looking south from same point
- Normal maximum level is about 2.0 metres above present water level according to marks on bridge piers
- The WSC recorded high level on Teslin Lake was elevation 685.611 metres (1961)
- The relationship between Teslin Lake and Johnsons Crossing water levels is as follows:

Teslin Lake (m)	Johnsons Crossing (m)	Diff. (m)
684.178	684.075	0.103
680.776	680.764	0.012
682.828	682.771	0.057

Summary for the Teslin River

- The highest water levels, both in Teslin and at Johnsons Crossing are reported by two sources to be what was measured as 3.0 to 4.0 metres above the present water level
- Earth slide on Teslin River caused the highest water level, this is about 3.0 to 4.0 metres above present level
- WSC level for Teslin Lake was elevation 681.7 metres on August 17, 1983

Pelly River Below Vangorda Creek and at Old Ferry Crossing

- Width at bridge: 105 metres
- One centre pier
- Low area on left bank that is 1.0 to 3.0 metres above present water level
- High silt bank on right
- Extensive riverbed gravel deposits downstream of bridge
- Floodplain 1,000 metres wide, or more
- Gauge 5.037 metres = 638.302 metres = 250 m^3/s
- Stones 2" to 4" Ø on floodplain 0 to 0.5 metres above water level
- Slope at bridge 0.07 in 140
- Photos 1-13 roadhouse, 1-14 Pelly River at ferry, 1-15 Pelly River at ferry
- Wide floodplain at old ferry crossing - 1 to 2 km
- River frequently changes course
- Photos 1-20, 1-21 from bridge to Faro, looking downstream

Ross River at Ross River

- Width: 85 metres
- Ground on right bank at confluence with Pelly River is 3.0 to 4.0 metres above present water level
- Photo 1-16 looking upstream
- Width at cableway for WSC metering section is 70 metres
- Photo 1-17 at cableway

- High water marks about + 2.0 metres, with some evidence of ice action at this level
- Gauge 3.35 metres today, = 697.95 = 470 m^3/s. Note: This does not check with the flow on the Pelly River below Vangorda
- Slope of Pelly River at Canol Bridge 0.02 in 129
- Photos 1-18 and 1-19 of Pelly River at Canol Bridge

Summary for Pelly River (Faro to Ross River Section)

- River meanders in a wide, U-shaped valley and changes course frequently

Pelly River at Pelly Crossing

- Width at old ferry slip is 160 metres. Width at bridge is greater (220 metres)
- Right bank + 10 metres
- Left bank 6.0 metres high. Old church on left bank
- Photo 1-29 looking at right bank, 1-30 looking downstream at bridge
- Long time resident of Pelly Crossing reported 1982 was highest water year (+ 3.5 metres). Sometimes there has been an ice jam at bend about 2 km upstream from old ferry. Never floods settlement
- Downstream of bridge, the banks are only 2.5 to 3.0 metres above water level, however, on the right bank there is a terrace, about 50 metres back from the river edge which rises about 8 metres above the water
- Photo 1-31 looking to right bank, 1-32 downstream
- Width: 190 metres
- Photo 1-33 about 6 km downstream of old ferry crossing looking at left bank
- Photo 2-1, 2-2 view of Pelly River Bridge looking downstream. Photo 2-3 looking upstream
- On August 30, 1983 the reading on the WSC gauge at Pelly Crossing was 2.54 metres, elevation 460.83. This corresponds to a flow of about 720 cubic metres per second

Pelly River 3 km Upstream of Bradens Canyon

- Banks 4.0 metres high on both sides
- Photo 1-36 looking across to left bank

Pelly River Upstream of Granite Canyon

- Width: 140 metres
- Right and left bank both 7.0 to 9.0 metres high
- 1983 high water mark + 3.0 metres or a little less
- Photos 2-36 across, 2-37 downstream

Stewart River, 5 km Upstream of Mayo River

- Width: 195 metres
- Right bank + 8 metres, left bank low (+ 2.0 metres)
- High water mark + 2.5 metres
- Photo 2-32 across

Stewart River at Mayo

- Width: 160 metres at WSC gauge
- Left bank + 3.0 metres, right bank + 4.0 metres to top of dyke
- Downstream of point, left bank is high
- Photos 2-33 across, 2-34 downstream
- This year water came to within 0.5 to 1.0 metres of the top of sandbags around gauge (and dyke was raised)
- WSC gauge on August 30, 1983 was 5.491 metres, corresponding to a flow of about 850 cubic metres per second
- The recorded high gauge reading for 1983 was 9.480 metres; or elevation 488.952 metres

Stewart River, 2.5 km Downstream of Mayo River

- Right bank is high and has Indian burial ground
- Old settlement on left bank. Ground + 3.0 metres

Stewart River, 2.0 km Downstream of Seventeen Mile

- High right bank
- Left bank + 6.0 metres

Stewart River, 8.0 km Upstream of Stewart Crossing

- Width: 120 metres
- Right bank (highway) at least 10 metres above water
- Left bank low (+ 2.0 metres)
- Photo 2-35 looking from highway across to gravel bar. Note Black Spruce

Stewart River at Stewart Crossing

- WSC gauge level on August 30, 1983 was 15.08 feet, corresponding to a flow of about 900 cubic metres per second
- Width at bridge: 150 metres
- High bank on right side
- Left bank 3.0 metres. Photo 2-4 looking downstream

Stewart River, 5 km Downstream of Stewart Crossing

- River well contained by banks on both sides at all river stages
- Photos 2-5 upstream, 2-6 downstream

Stewart River, 14 km Downstream of Stewart Crossing

- Left bank low
- Photo 2-7 looking across at left bank

Stewart River, 17 km from Stewart Crossing

- Width: 210 metres
- Left bank + 4.0 metres above water level
- Photos 2-30 across, 2-31 downstream

Stewart River at Steamboat Bar

- Width to island bar: 225 metres
- Photos 2-8 across, 2-9 upstream
- Right bank 4.0 metres above present water
- Left bank low
- The right bank shows evidence of ice action to + 3.0 metres above present water

Stewart River, 5.0 km Upstream of McQuesten River Confluence

- Width: 200 metres
- Right bank 5.0 metres above water level
- Left bank about the same or a little lower
- McQuesten River has lower banks
- Photo 2-27 downstream, 2-28 across
- Photo 2-29 gas station at McQuesten

- Fish camp on right bank

Klondike River, 9 km Upstream of Rock Creek

- Width: 65 metres
- Right bank low (+1.0 - +2.0 metres)
- Road on left bank (highway) + 3.0 metres
- Photos 2-23 upstream, 2-24 downstream

Klondike River at Rock Creek

- Photos 2-10 right bank, 2-10A left bank
- Right bank 1.5 to 2.0 metres above water
- Left bank a little lower 1.0 to 1.5 metres above water
- Width: 110 metres

Klondike River Above Bonanza Creek

- WSC gauge 1.341 metres on August 29, 1983 = elevation 320.668 = flow of about 115 cubic metres per second
- Photo 2-25 Bonanza Creek, 2-26 old dredge

A.3 LOCAL RESIDENT INTERVIEWS

Bradley Brothers, Pelly Farm

- Came in 1954
- Ice jam on the Yukon River in 1957 backed up the Pelly River and put ice on the flats at Pelly Farm
- High flow year was 1964 when water came to within 2 feet of the top of the bank. This flood caused considerable erosion
- Ice jam took out trees along the bank
- In 1927 it was reported that an ice jam on the Yukon put water on the flats at Fort Selkirk and at Pelly Farm. Anglican church records could verify this
- An ice jam at Pelly Crossing has caused the river to flow in a low area to the south of the town
- Ice thickness on the Pelly River at Pelly Farm ranges around 30" but can get to 4 feet
- Pelly Crossing contact is Dan van Bibber

Break-up Dates Pelly River at Pelly Farm

1956	May 6	1970	May 7
1957	May 8	1971	May 6
1958	Apr 28	1972	May 14
1959	May 14	1973	May 5
1960	Apr 30	1974	May 12
1961	May 10	1975	May 6
1962	May 28	1976	May 4
1963	May 4	1977	May 6
1964	May 25	1978	May 2
1965	May 3	1979	May 3
1966	May 6	1980	May 2
1967	May 10	1981	May 2
1968	May 6	1982	May 14
1969	Apr 29	1983	May 4

- Dates are when the ice went out. First movement one or two days previously
- There are often two or three slugs of ice from upstream jams
- Present water level to top of right bank at Pelly Farm 3.47 metres
- 1983 HWL was 1.12 metres from top of right bank
- Width: 200 metres
- Photos 1-34 upstream, 1-35 downstream

Father Vara - Ross River

- Came periodically around 1950 and stayed continuously since 1967
- The worst flood he can remember was in 1972; however, he understood that the water was a little higher sometime in the early 1960's
- The 1972 high water mark was surveyed to be 1.9 metres above the water level on August 27, 1983
- In 1976 there was an ice jam downstream of the town and ice reached to the Catholic church residence
- Canol Road repaired in 1968 and the present townsite began
- River is open at Faro 2-3 weeks before Ross River

Les Allen - Teslin, Former Resident on River Downstream of Johnsons Crossing

- Ice does jam at the Johnsons Crossing Bridge when a pan comes down from the lake. Ice has come up on the picnic area under the bridge (left bank). There used to be pylons in the river, upstream and downstream of the bridge and ice jams were more frequent then.
- Never any evidence at Johnsons Crossing of downstream ice jams which caused an increase in water level
- Possible location of ice jam is at the "Chute" about 5 km upstream of Swift River
- Only about the lower 4 km of Teslin Lake ice goes down the river
- Lake ice thickness known to reach 6 feet but generally does not get to more than 3 feet
- At Johnsons Crossing the water level has submerged the base of the pier so that a small boat could navigate between the two vertical columns. This occurred in the 1960's (3.0 to 4.0 metres above water level)
- Wind shifts ice on the lake and causes it to pile up on shore
- In Teslin the high water mark is known to be about 3.0 to 4.0 metres above the present level

Calvin Clifford, Town Manager, Mayo

- Flooding at Mayo starts on the southeast part of town at the Indian village
- This year the water backed up behind Fraser Falls (no ice) and flooded the floors of some houses at Nogold Creek
- Ice jams have occurred at Fraser Falls in the past
- Dyke along the Mayo River is low at the north end
- Ice remains on the Stewart in front of Mayo longest, open upstream and downstream
- Highest water was in 1936
- No known ice jam locations downstream on Stewart

Les Boisvert - NCPC - Mayo

- Mayo River breaks up before the Stewart
- Ice from the Mayo River sometimes piles up on the Stewart and causes the Mayo River to flood
- NCPC current practice is to keep Wareham Lake low prior to spring break up and build up storage during the spring run-off, thereby avoiding high flows in the Mayo River

Charlie Randall

- Ice jams known to occur on the Yukon River downstream of Dawson at Twelve Mile where the river narrows, also at Fifteen Mile
- Upstream of Dawson, common locations are Coffee Creek and Kirkman Creek
- Ice jams on the Stewart River known at: Wildcat Slough, Icechest Reef, Chromartie Chute, Jackman Chute and Devils Elbow
- Floods have caused considerable river bank erosion at the confluence of the Yukon and Stewart Rivers. The HBC store has been moved two or three times
- At Five Finger Rapids the ice has been piled up about 30 feet high on the river banks
- Coffee Creek - water up to cabin roof
- Klondike breaks up first and this often triggers the breakup at Dawson
- Worst floods in Dawson have been caused by ice jams below Dawson - i.e. at Twelve Mile, Fifteen Mile
- Ice jams have generally been in narrow river sections as opposed to wide, shallow areas with sand bars, islands
- Jam at Dawson may raise level 10 to 12 feet

Monty Alford - Water Survey of Canada

- Ice jam at Dawson is generally at a point above Fort Reliance. Other known locations for ice jams on the Yukon River are: Coffee Creek, downstream Fort Selkirk, Selwyn, below White River confluence (first bend)
- Teslin River, ice jam just upstream of Teslin Crossing to Livingstone Creek
- Pelly River - not known
- Stewart River, ice jams sometimes just below Mayo but not a problem - bend between McQueston and Stewart Crossing
- Klondike jam at Rock Creek
- Takhini - gentle river - no ice problems

G.I. Cameron - NWMP

- Went to Dawson in 1925, stayed until 1928, then spent 14 years at Fort Selkirk
- Flood in Dawson that spring due to ice jam below Moosehide
- Ice jams known to occur on the Stewart below Mayo. Location not known
- Coffee Creek (below) known to be frequent flood at farm
- Stewart Island (Crossing)
- Fort Selkirk - once over the banks. Ice jam was about 2 miles downstream
- Yukon Crossing would flood frequently in the late fall or early winter - (ice dam). Buildings flooded to 2 to 3 feet
- Carmacks no problems
- Ross River - old town no problem, new town yes
- Forty Mile known to flood frequently
- Thistle Creek flooded
- Kirkman Creek ice jam on bar. Shallow water
- Minto OK (no flooding)
- MacMillan River, not known to flood
- Sometimes ice jam above Granite Canyon on the Pelly River
- Ice jams known on the Pelly River below the crossing
- Yukon and the Pelly break up about the same time
- Ice may have jammed at Hells Gate about 10 miles upstream of Fort Selkirk. Shallow water
- Fort Selkirk established in 1848.

Brian Laird - City of Whitehorse

- Tom Blench report on Marwell flooding
- Monenco Report to NCPC re: Marwell
- City recognize Marwell problem
- Whitehorse used to flood up to 1st Avenue (City Hall)
- Marwell is presently zoned industrial/commercial however, existing housing can stay as a non-conforming use

Jack Andison - Former Mayo Area Resident

- Resident in the Mayo and Elsa areas from 1929 to 1970
- The worst flood he remembers was in 1936 when the water reached a depth of 4.5 feet in the town; more in the low areas. There was an Indian villge about two miles downstream of Mayo that was destroyed in the 1936 flood and never re-built
- Other significant floods occurred in 1947 and 1955
- Ice has been known to jam at the narrow point of land on the bend in front of the town (at the WSC gauging station)
- The ice jams on the Mayo River at the mouth have caused flooding problems in "recent" years

Frank Goulter - Carmacks

- Remembers three floods when water came into the town; 1910, sometime in the late 1920's and in 1958. Ice jams were never the cause of flooding (?)
- There can be an ice dam form in the fall when the weather at the time of freeze-up is warm

APPENDIX B

YUKON RIVER BASIN

FLOOD RISK STUDY

RESEARCH OF YUKON ARCHIVES IN WHITEHORSE, 1902 TO 1945

APPENDIX B

YUKON BASIN FLOOD RISK STUDY - ARCHIVES RESEARCH

B.1 INTRODUCTION

This review of the Yukon Archives in Whitehorse was undertaken by Miss Diane Lister to determine if there had been any severe floods in the Yukon River Basin prior to the period of gauge records by the Water Survey of Canada. Data that could be useful in understanding the break-up and flooding process were recorded. The time frame covered by this research is 1902 - 1945. Reference material consisted of:

- White Pass Meteorological Records, Series VIII-1, Volumes 1 to 29.
- Whitehorse Star.
- "Exploring the Yukon River", by A. Satterfield, Douglas & McIntyre Ltd., 1979.

A review of the Yukon Archives in Dawson City had previously been carried out by the Dawson City Museum & Historical Society for Indian and Northern Affairs Canada. The results of this work are summarized in their report "Historical Review of Dawson City Flood Data, 1898-1975", dated March, 1981.

B.2 GENERAL COMMENTS

The following are some general comments pertaining to the archives research program.

- Anglican Church records were being compiled by Archive staff and thus not available for viewing.
- Newspaper coverage of ice jams and minor flooding became increasingly sparse after about 1920, when only the larger floods were mentioned.
- Ice seems to go out on the Klondike, Stewart and Pelly Rivers before ice is cleared on the Yukon River at the respective confluences. This results in a piling up of ice at the mouths of these rivers.
- The ice often holds longer at Coffee Creek than at any other point on the Yukon River; resulting in a build-up of broken ice behind the solid sheet (and flooding).
- In this appendix, the term "ice jam" means that the broken ice stopped moving down the river for a period of time. This may, or may not, have been accompanied by a rise in water level.

B.3 COMMENTARY ON HISTORIC FLOODING

The following summary contains comments relative to flooding on the Yukon River system. The period covered is 1902 to 1945.

1902: Ice out in Whitehorse April 21, Lake Laberge clear May 28, ice out on Pelly River May 1, Stewart and White Rivers open May 6, Yukon River at Stewart River broke May 13, at Dawson on May 11.

Ice jams: between Tantalus and Five Finger Rapids, at Five Finger Rapids, Rink Rapids, Fort Selkirk, Selwyn, Stewart River. The ice jam at Fort Selkirk was reported as being 40 feet high.

1903: Ice out in Whitehorse May 3, Lake Laberge clear June 5.

Ice jams: above Tantalus River, at Five Finger Rapids, Hells Gate, above Fort Selkirk.

1904: Ice out in Whitehorse April 26, Lake Laberge clear June 10, ice out in Dawson May 7.

Ice jams: below Big Salmon, at Hells Gate, 4 miles downstream of Yukon Crossing, below Fort Selkirk, at Ogilvie and Forty Mile. Horses and feed lost at Fort Selkirk due to high water. At Forty Mile the residents had to "head for the hills".

1905: Ice out in Whitehorse April 17, Lake Laberge clear May 26, ice out on Klondike May 6, Yukon at Dawson May 10.

Ice jams: at Five Finger Rapids, Yukon Crossing.

1906: Ice out in Whitehorse April 25, Lake Laberge clear June 5, Pelly River out May 7, Dawson out May 11.

Ice jams: between Tantalus and Carmacks, downstream of Yukon Crossing and Fort Selkirk, at Coffee Creek, below Stewart River.

1907: Ice out in Whitehorse May 2, Lake Laberge clear June 5, Big Salmon ice out May 7, Dawson May 5.

Ice jams: Yukon Crossing, Hells Gate, Fort Selkirk. The flood at Yukon Crossing due to the ice jam resulted in water nine feet deep at the roadhouse and four feet deep at the operator's cabin.

1908: Ice out in Whitehorse April 24, Pelly River ice out May 5, ice out in Dawson May 7.

Ice jams: In front of the White Pass depot at Whitehorse, at Five Finger Rapids, Yukon Crossing, Coffee Creek, Stewart River. Stewart River jammed at the mouth.

1909: Ice out in Whitehorse May 8, Lake Laberge clear June 15, Stewart River open May 10, ice out in Dawson May 11.

Ice jams: five miles below Big Salmon, between Big Salmon and Tantalus, at Five Finger Rapids, Rink Rapids, Yukon Crossing, Hells Gate, Fort SelkirK.

1910: Ice out in Whitehorse April 29, Selwyn station open May 14, Coffee Creek open May 17, White River open May 7, Dawson out May 7.

Ice jams: at Miles Canyon, Big Bend, Hootalinqua, Rink Rapids, Yukon Crossing, Minto, Hells Gate, Fort Selkirk, Klondike River Bridge.

1911: Ice out in Whitehorse May 7, Lake Laberge clear June 9, the Thirty Mile open April 28, Pelly River open May 4, ice out of Stewart River May 9.

Ice jams: five miles south of Whitehorse, at Big Salmon, Yukon Crossing, Fort Selkirk.

1912: Ice out at Whitehorse April 18 and at Dawson May 10.

Ice jams: at Whitehorse Rapids, Hootalinqua, between Carmacks and Little Salmon, above Five Finger Rapids, at Yukon Crossing, Hells Gate, Fort Selkirk, Ogilvie.

1913: Ice out in Whitehorse April 26, Lake Laberge clear June 12, Pelly River ice out May 18, Yukon River ice out at Stewart River May 19, Dawson May 14, Klondike River out May 9.

Ice jams: One mile above Big Salmon, at Yukon Crossing, between Yukon Crossing and Minto, below Coffee Creek, five miles below Stewart River.

1914: Ice out in Whitehorse April 22, Big Salmon River open May 9, White River open May 11, Klondike River open May 8.

Ice jams: at Whitehorse Rapids (10 to 18 feet high), between Little Salmon and Carmacks, at Fort Selkirk.

1915: Ice out in Whitehorse April 4 (earliest in history).

Ice jams: between Little Salmon and Carmacks, 0.5 miles below Yukon Crossing, at Fort Selkirk, Pelly Crossing roadhouse, mouth of White River, mouth of Stewart River and three miles below Ogilvie.

1916: Ice out in Whitehorse April 24, Lake Laberge clear May 25, ice out at Dawson May 2.

Ice jams: at Whitehorse and four miles downstream, three miles downstream of Carmacks, four miles below Yukon Crossing, below Fort Selkirk (channel running through sloughs), near Pelly Crossing roadhouse, at Coffee Creek and Ogilvie.

1917: Ice out in Whitehorse April 30 and in Dawson May 5.

Ice jams: three miles downstream of Big Bend.

1918: Major flood at Yukon Crossing from ice jam on the Yukon River. Buildings flooded up to the roof. Clarkes roadhouse flooded to depth of one foot above the second storey.

1919: Ice out in Whitehorse April 22.

1920: Ice jams: one mile above Big Salmon, nine miles below Yukon Crossing, below Fort Selkirk, at Pelly Crossing roadhouse, above the mouth of the White River, one mile below the Stewart River and on the Stewart River at the mouth.

1921: Ice out in Whitehorse April 25 and in Dawson May 12.

Ice jams: at White Pass dock and below Whitehorse, three miles below Big Bend, Yukon Crossing, below Fort Selkirk, at Pelly Crossing roadhouse, at mouth of Stewart River and at Forty Mile.

1922: Ice out in Whitehorse April 27, in Dawson May 14 and on Klondike River May 11.

Ice jams: between Hells Gate and Yukon Crossing (several), at and above Fort Selkirk, Pelly Crossing roadhouse, Coffee Creek, below Stewart River, above Ogilvie.

1923: Ice out in Whitehorse April 23, Lake Laberge clear May 26, ice out at Sixty Mile May 7, Dawson May 10, Forty Mile May 11 and on the Klondike River May 6.

Ice jams: at Yukon Crossing (flood up to porch on White Pass office), both upstream and downstream of Fort Selkirk, at the mouth of the Pelly River. Water two feet deep in the White Pass office at Forty Mile.

1924: Ice out in Whitehorse April 16, at Big Salmon May 5, at Dawson May 8, at Forty Mile May 3. Klondike River went out April 29.

Ice jams: at Whitehorse, Five Finger Rapids, Hells Gate, upstream and downstream of Fort Selkirk, mouth of Pelly River, downstream of Stewart River, Ogilvie.

1925: Ice jams: on Big Salmon River, between Tantalus and Carmacks, downstream of Yukon Crossing, at Fort Selkirk, at Stewart River (water ran through slough).

1926: Ice out in Whitehorse April 1, at Sixty Mile April 27, Dawson May 3.

Ice jams: five miles downstream of Whitehorse, at Big Salmon, 0.5 miles below Fort Selkirk, at mouth of Pelly River, Coffee Creek, Stewart River and at the mouth of the Stewart River and the Klondike River.

1927: Ice out in Whitehorse April 27, Dawson May 13 and Forty Mile May 11. Ice out of the Stewart River at Mayo May 18.

Ice jams: at Yukon Crossing, two miles below Fort Selkirk, one mile upstream of Coffee Creek, at Stewart River and at the mouth of the Stewart River.

1928: Ice out in Whitehorse April 26, Dawson May 9 and Forty Mile May 6.

Ice jams: at Big Bend, Yukon Crossing, 15 miles downstream of Yukon Crossing, between Hells Gate and Fort Selkirk, at Fort Selkirk. Stewart River jam at the mouth (Yukon River solid cover on May 9). Klondike River jam near Bear Creek.

1929: Ice jams at Hells Gate and two miles below Stewart river.

1930: Ice out in Whitehorse April 23, Lake Laberge clear May 29, Hootalinqua clear May 11, Dawson May 10. Ice moved on Stewart River at Mayo on May 11.

Ice jams: five miles upstream of Five Finger Rapids, at Hells Gate, four miles below Fort Selkirk, on Pelly River at mouth (Yukon River solid May 3), below Ogilvie.

1931: Ice out in Whitehorse April 24, Big Salmon May 10, Tantalus to to Carmacks April 30, Ogilvie May 8, Dawson May 12, Klondike River May 6.

Ice jams: at Fort Selkirk and two miles below Fort Selkirk, two miles below Stewart River.

1932: Ice jams at Five Finger Rapids, two miles below Fort Selkirk, Coffee Creek

1933: Ice out in Whitehorse May 2, Tantalus to Carmacks May 4, Sixty Mile May 5, Dawson May 9, Klondike River May 4, Stewart River at Mayo May 15.

Ice jams: one mile upstream of Big Salmon, on Pelly River at the mouth, on Stewart River at the mouth, on Yukon River below Stewart River.

1934: Ice out in Whitehorse April 24, Dawson May 2 and Mayo May 8.

Ice jams: at Yukon Crossing, Fort Selkirk, Coffee Creek, Ogilvie and on the Stewart River at the mouth.

1935: Ice out in Whitehorse April 29, Dawson May 15.

Ice jams: at Yukon Crossing, Fort Selkirk, Coffee Creek, four miles below Stewart River.

1936: Ice out in Whitehorse April 30, Dawson May 5, Klondike River April 30.

Ice jams: below Fort Selkirk, Selwyn, Coffee Creek. On May 15, ice jams were located:

- From Selwyn to a point eight miles downstream
- From White River to a point three miles upstream of Coffee Creek.

This was the worst flood experienced (so far) at Coffee Creek. Only the roofs of the houses were visible. Flooding occurred as the ice jam moved out.

1937: Ice out in Whitehorse April 20, Dawson May 10, Klondike River May 6. Yukon river at Stewart River still holding May 10.

Ice jams: at Fort Selkirk and on the Stewart River at the mouth.

1938: Ice out in Whitehorse April 10, Dawson May 12, Klondike River May 8, Stewart River at Mayo May 12.

Ice jams: two miles downstream of Fort Selkirk, below Stewart River, on Stewart River at the mouth.

1939: Ice out in Whitehorse April 20, Coffee Creek May 13, Dawson May 12, Klondike River May 4, Mayo May 16.

Ice jams: between Tantalus and Carmacks, Coffee Creek, one mile downstream of Stewart River, on Stewart River at the mouth, below Dawson, on Klondike River at the mouth.

1940: Ice jams at Five finger Rapids, Rink Rapids, Hells Gate, Fort Selkirk, on Pelly river at the mouth, below Stewart River.

1941: Ice out in Whitehorse April 8, Dawson April 30. Reported as a very warm spring - no ice jams.

1942: Ice out in Whitehorse April 16, Dawson May 6.

Ice jams: Ice from the Stewart River jammed on the Yukon River below the settlement.

1943: Ice out in Whitehorse April 23, Dawson May 2.

Ice jams: on the Yukon River in front of the settlement at Stewart River.

1944: Ice out in Whitehorse April 15, Lake Laberge clear May 18, Dawson May 5.

Ice jams: downstream of Dawson.

1945: Ice out in Whitehorse April 16, Dawson May 16, Klondike River May 11.

Ice jams: Coffee Creek, at mouth of the Klondike River.

APPENDIX C

YUKON RIVER BASIN

FLOOD RISK STUDY

BIBLIOGRAPHY

APPENDIX C

BIBLIOGRAPHY

Dawson City Museum & Historical Society
"Historical Review of Dawson City Flood Data, 1898 - 1975", March, 1981.

Environment Canada, Atmospheric Environment Service
"Canadian Climatic Normals, 1951 - 1980, The North - Y.T. and N.W.T."

Environment Canada, Inland Waters Directorate
"Historical Streamflow Summary to 1979, Yukon and Northwest Territories"

"Surface Water Data, 1980, Yukon and Northwest Territories"

"Surface Water Data, 1981, Yukon and Northwest Territories"

"Magnitude of Floods, British Columbia, Yukon Territory", three volumes, September, 1982.

Environment Canada, National Water Research Institute
"Proceedings of Workshop on Hydraulic Resistance of River Ice", September 23-24, 1980

Fenco Consultants Ltd.
"Yukon Flood Study", May 1974

"Yukon River Ice Study - Dawson, Yukon Territory", October, 1976

Geological Survey of Canada
"Map 1398 A, MacMillan River, Yukon - District of Mackenzie - Alaska", compiled by H. Gabrielse, D.J. Templeman - Kluit, S.L. Blusson and R.B. Campbell, 1980.

"Memoir No. 5 - Preliminary Memoir on the Lewes and Nordenskiold Rivers Coal District, Yukon Territory", by D.D. Cairnes, 1910.

"Memoir 284 - Yukon Territory, Selected Field Reports of the Geological Survey of Canada, 1898 to 1933", compiled by H.S. Bostock, 1957.

"Memoir 200 - A Reconnaissance of Pelly River Between MacMillan River and Hoole Canyon, Yukon", by J.R. Johnston, 1936.

"Memoir 189 - Carmacks District, Yukon" by H.S. Bostock, 1956.

"Memoir 312 - Whitehorse Map Area, Yukon Territory, 105D", by J.O. Wheeler, 1961.

Geological Survey of Canada (continued)

"Memoir 364 - Geology of Nash Creek, Larsen Creek and Dawson Map Areas, Yukon Territory", by L.H. Green, 1972.

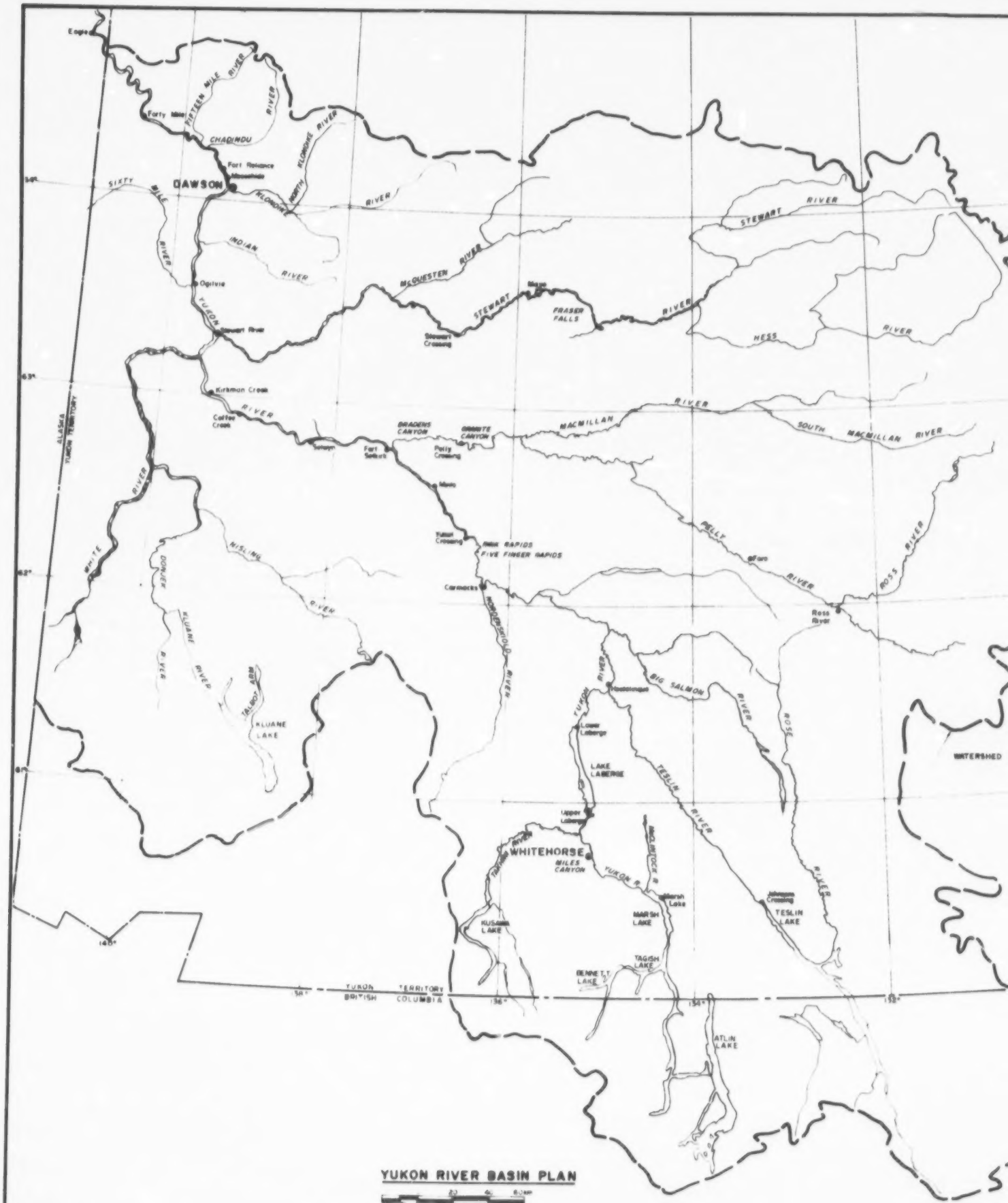
Indian and Northern Affairs
"Dawson Flood Study - Ice Jam of May 3, 1979; 1980 and 1981 Breakup" by Mel Orecklin, P.Eng.

T.D. Kent Environmental Consultant
"A Survey of the Timing and Progression of the Ice Break-up on the Yukon River, 1982", by T.D. Kent.

"A Survey of the Timing and Progression of the Ice Break-Up on the Yukon River, 1983", by T.D. Kent.

Northern Affairs and National Resources, Water Resources Branch
"Yukon River Basin Report", December, 1962.

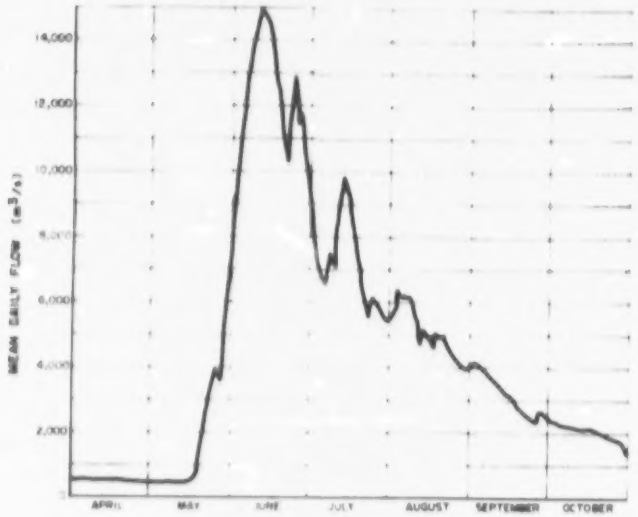
University of Alberta
"Spring Flood Forecasting for Mayo and Ross River, Yukon Territory" by Jac. P. Verschuren and D. Crawford, Department of Civil Engineering, April, 1976.


DAWSON
Fort Reliance
Eagle
Forty Mile
FIFTEEN MILE RIVER
CHADINDU
KLONDIKE RIVER
NORTH
SIXTY MILE RIVER
INDIAN RIVER
Ogilvie
YUKON
Stewart River
McQUESTEN RIVER
STEWART RIVER
Mayo
FRASER FALLS
Stewart Crossing
HESS RIVER
Kirkman Creek
Cotton Creek
ALASKA
YUKON TERRITORY
WHITE RIVER
BRADENS CANYON
GRANITE CANYON
Selkirk
Fort Selkirk
Pelly Crossing
MACMILLAN RIVER
SOUTH MACMILLAN RIVER
Minto
Yukon Crossing
Hootalinqua
FIVE FINGER RAPIDS
PELLY RIVER
ROSS RIVER
Carmacks
Ross River
NISLING RIVER
DONJEK RIVER
KLUANE RIVER
TALBOT ARM
KLUANE LAKE
MOORE CREEK
BIG SALMON RIVER
ROSE RIVER
Lower Laberge
LAKE LABERGE
TESLIN RIVER
Upper Laberge
WHITEHORSE
MILES CANYON
YUKON R.
McCLINTOCK R.
Marsh Lake
MARSH LAKE
Johnsons Crossing
TESLIN LAKE
KUSAWA LAKE
TAGISH LAKE
BENNETT LAKE
ATLIN LAKE
YUKON TERRITORY
BRITISH COLUMBIA
WATERSHED
YUKON RIVER BASIN PLAN

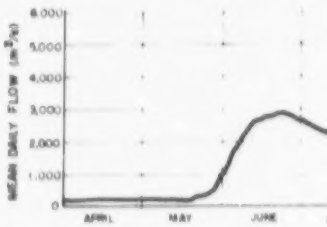
KEY PLAN

YUKON
B.C.

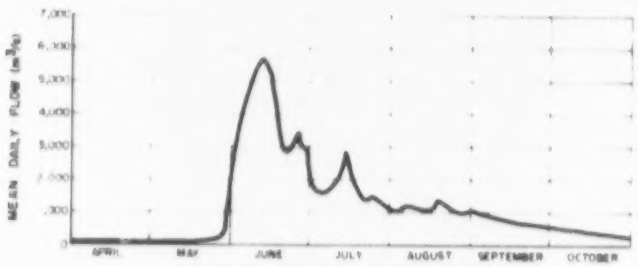
the uma group	ENVIRONMENT CANADA INLAND WATERS DIRECTORATE
	YUKON RIVER BASIN STUDY HYDROLOGY WORK GROUP REPORT NO. 1
	YUKON RIVER BASIN FLOOD RISK STUDY
	STUDY AREA LOCATION
	Date: October, 1983 — Figure 1



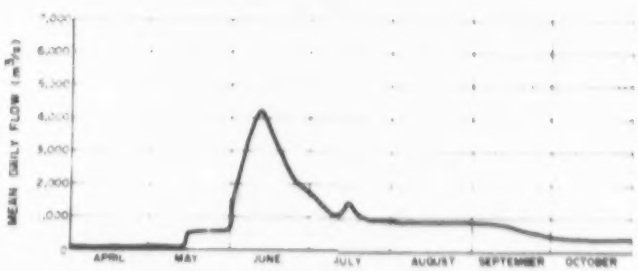
YUKON RIVER at DAWSON CITY
1964



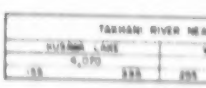
YUKON RIVER

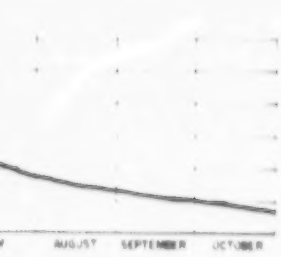


STEWART RIVER at the MOUTH
1964

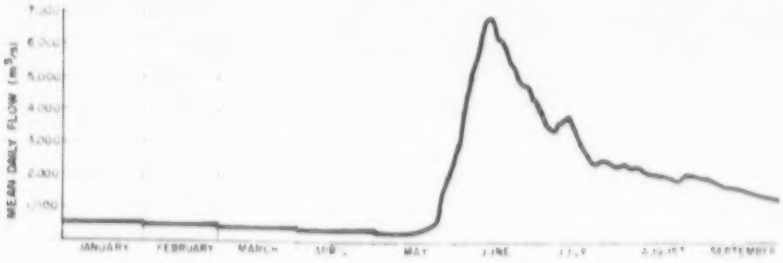


PELLY RIVER at PELLY CROSSING
1964

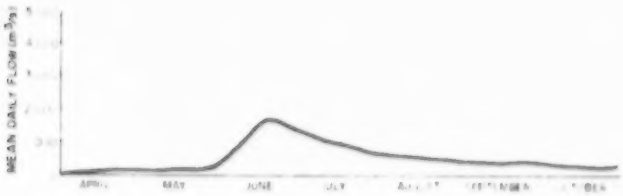




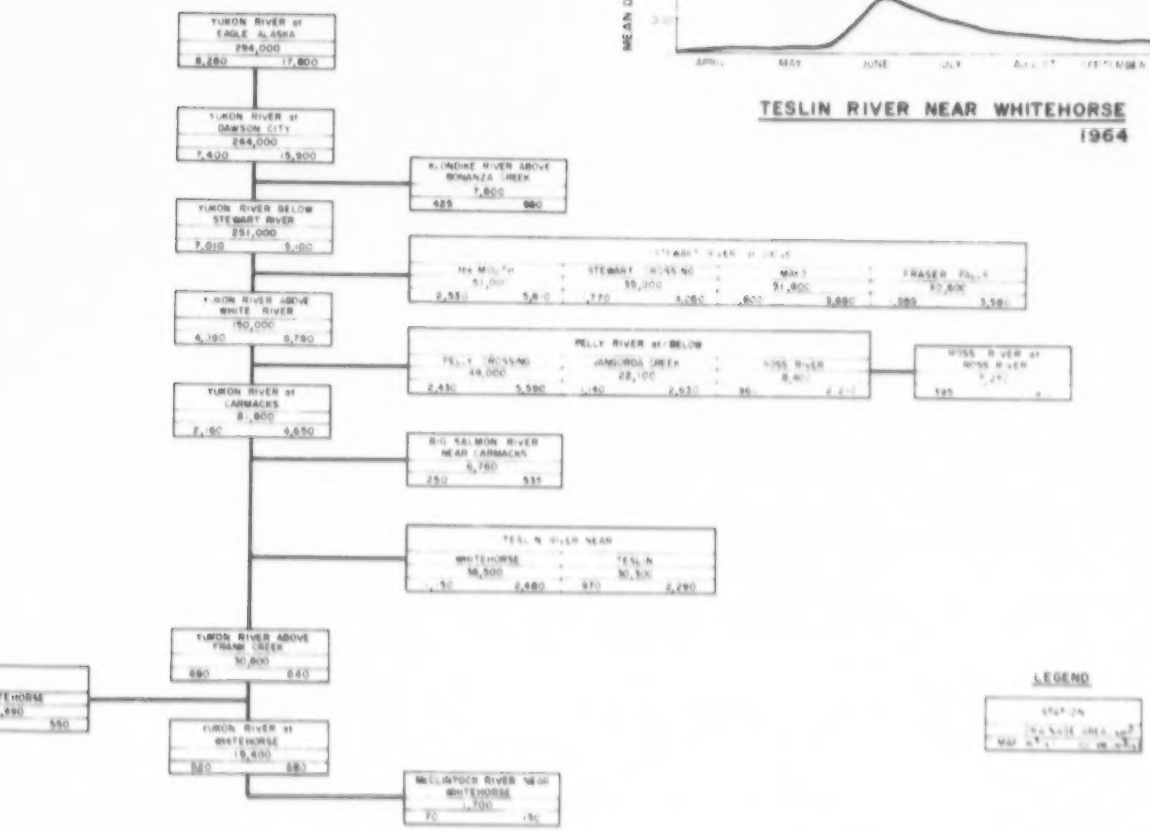
t CARMACKS
1964



YUKON RIVER ABOVE WHITE RIVER
1964



TESLIN RIVER NEAR WHITEHORSE
1964



PRINCIPAL WSC GAUGING STATIONS

NOTE: VALUES FOR THE MAF AND 100 YEAR FLOOD ARE BASED ON THE REGIONAL FLOOD FREQUENCY ANALYSIS EXCEPT FOR WHITEHORSE AND FRANK CREEK WHERE THE INDIVIDUAL STATION FREQUENCY DISTRIBUTION VALUES ARE USED

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INLAND WATERS DIRECTORATE

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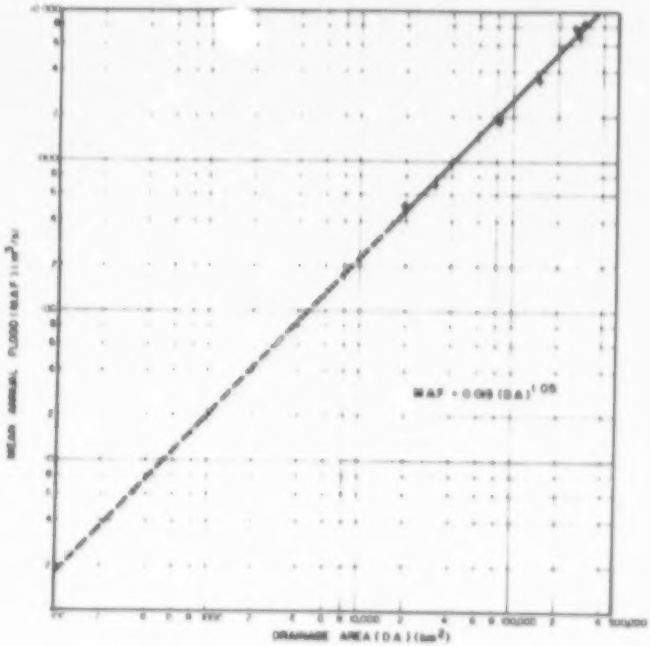
HYDROLOGY WORK GROUP REPORT NO 1

YUKON RIVER BASIN FLOOD RISK STUDY

FLOOD HYDROGRAPHS AND WSC GAUGING NETWORK

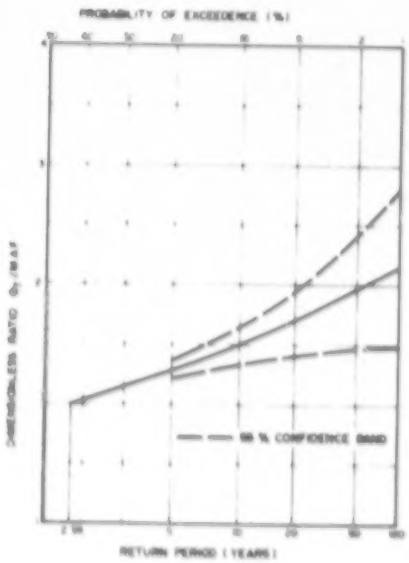
Date: October, 1983

Figure 2



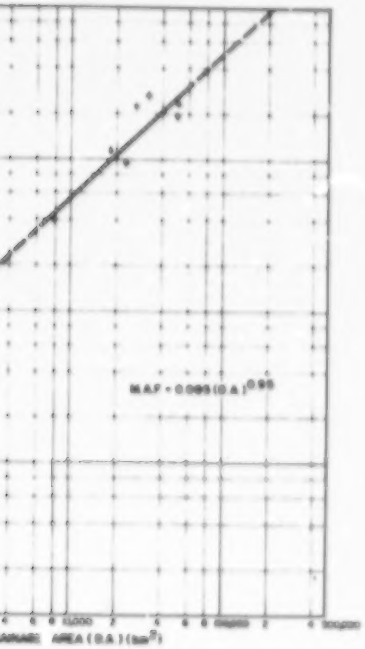
MEAN ANNUAL FLOOD vs DRAINAGE AREA

REGION 1



REGIONAL FLOOD FREQUENCY

REGION 1

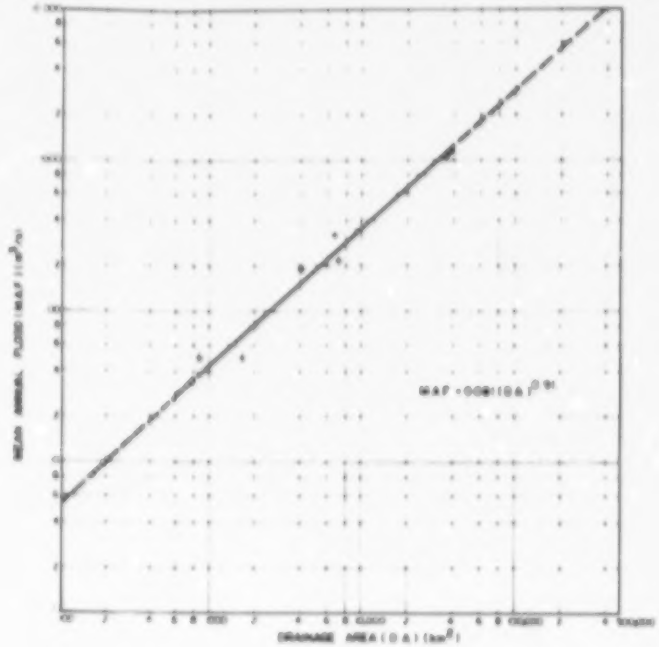


OOD vs DRAINAGE AREA

REGION 2

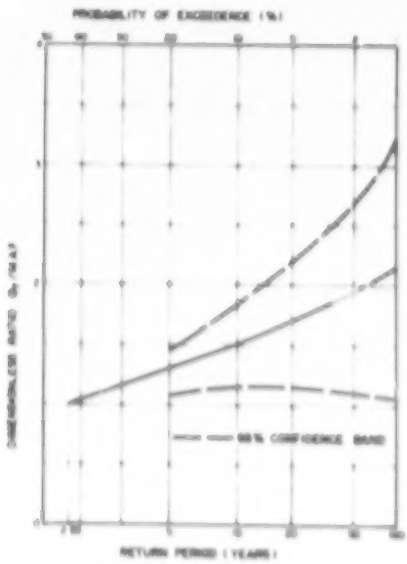
LOOD FREQUENCY

REGION 2



MEAN ANNUAL FLOOD vs DRAINAGE AREA

REGION 3



REGIONAL FLOOD FREQUENCY

REGION 3

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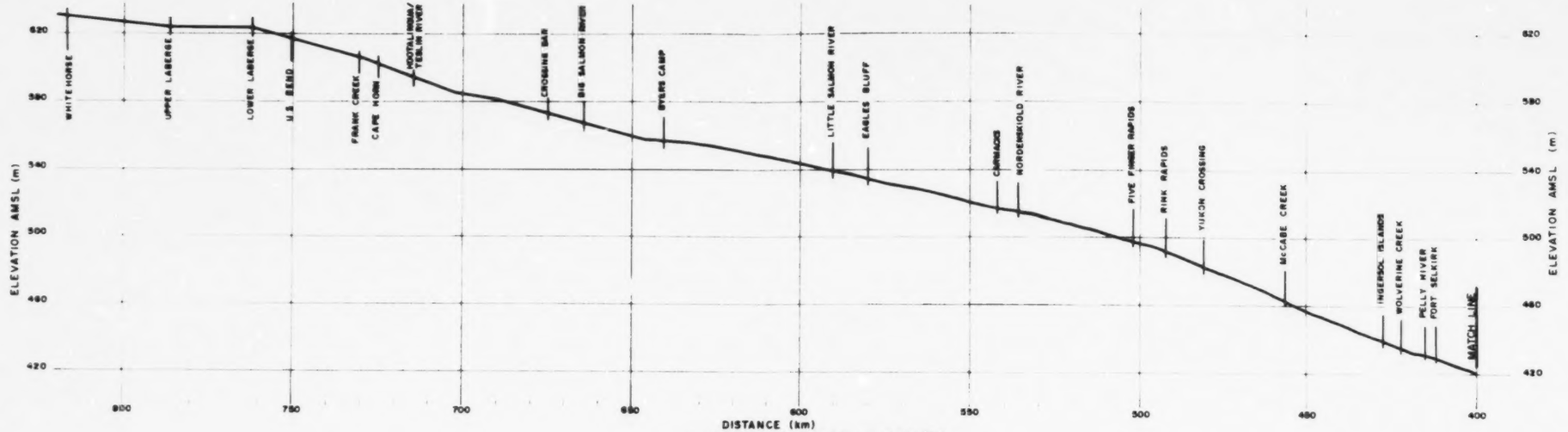
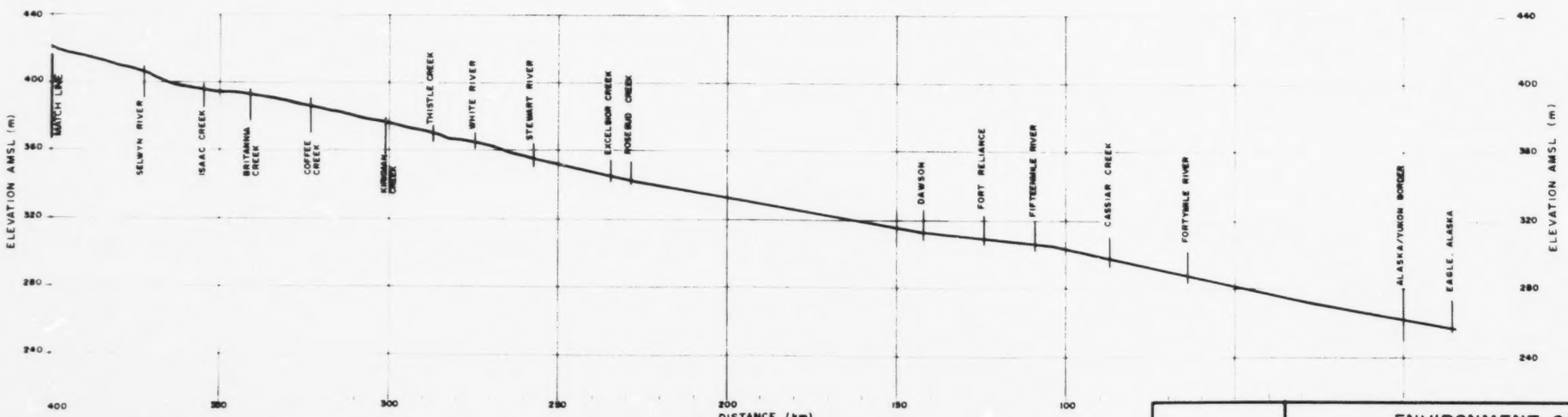
	YUKON RIVER BASIN FLOOD RISK STUDY
	REGIONAL FLOOD FREQUENCY ANALYSIS
	Date: October, 1983 — Figure 3



YUKON RIVER PROFILE (CON'T.)



YUKON RIVER PROFILE

SCALE HORIZ 0 10 20 30 km

VERT 0 30 60 90 m

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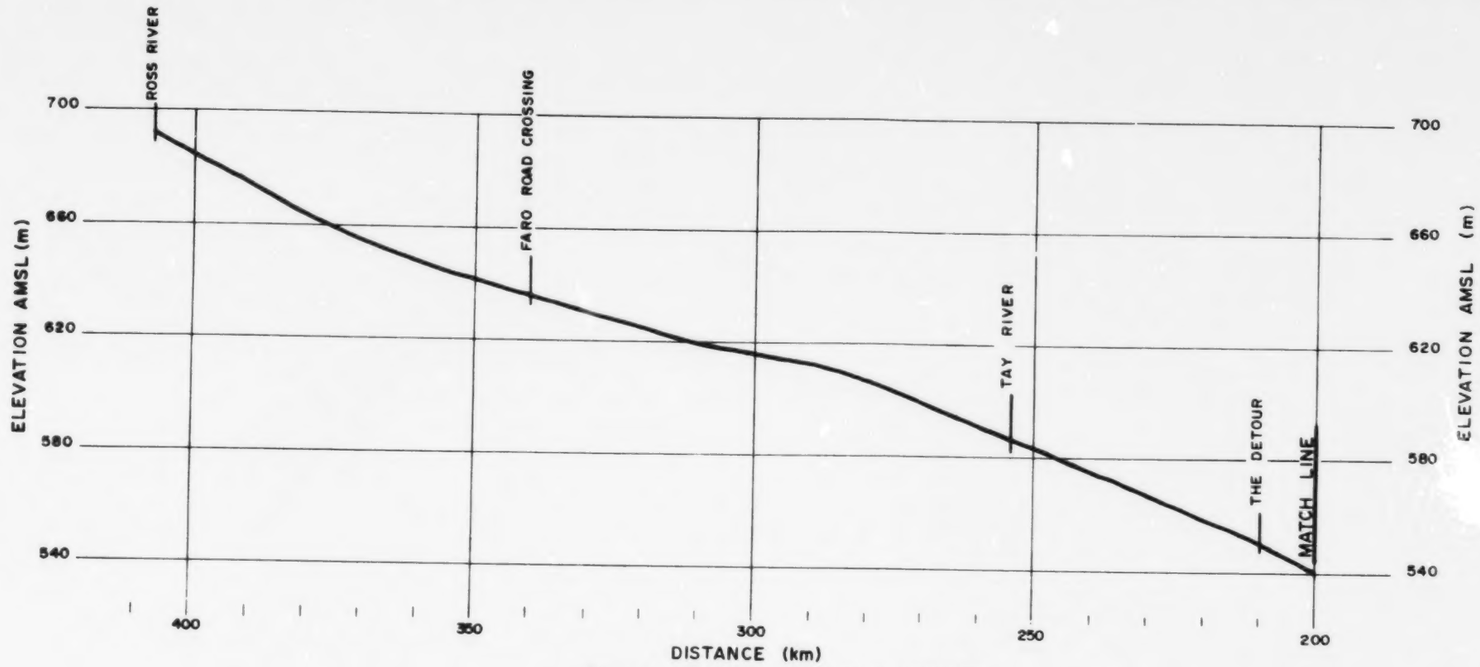
HYDROLOGY WORK GROUP REPORT NO. 1

YUKON RIVER BASIN FLOOD RISK STUDY

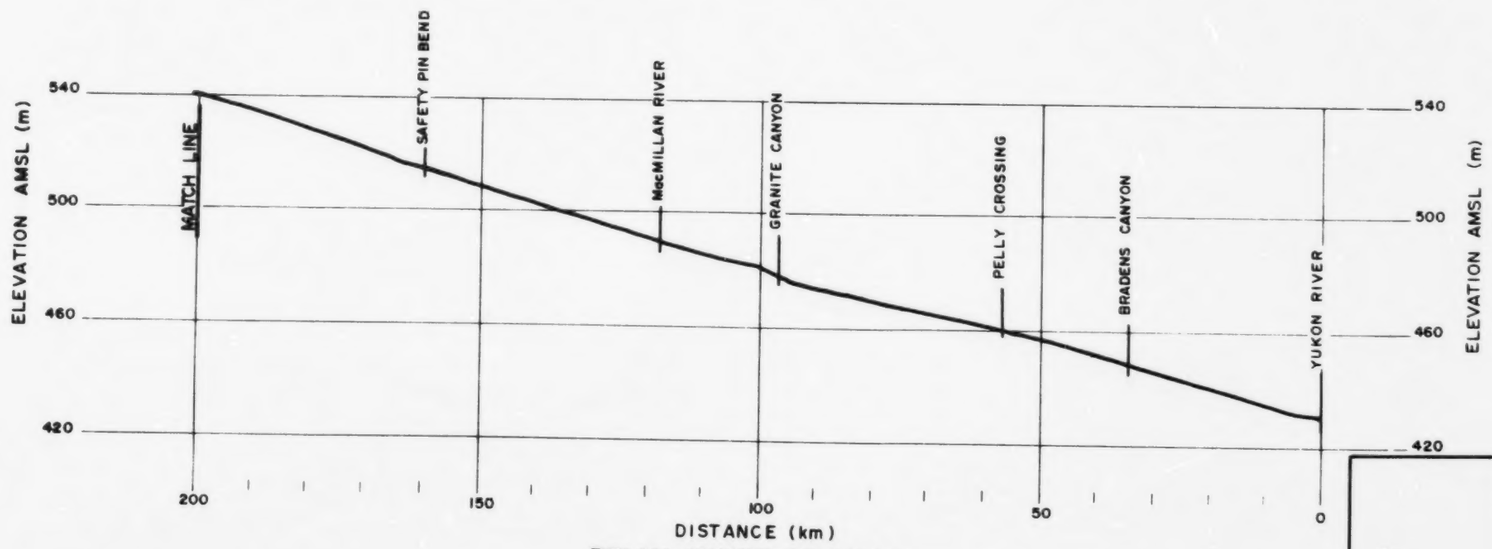
YUKON RIVER PROFILE

Date: October, 1983

Figure 4



PELLY RIVER PROFILE (CON'T)



PELLY RIVER PROFILE

SCALE
HORIZ 0 10 20 30km (10 5)
VERT 0 20 40 60m (20 10)

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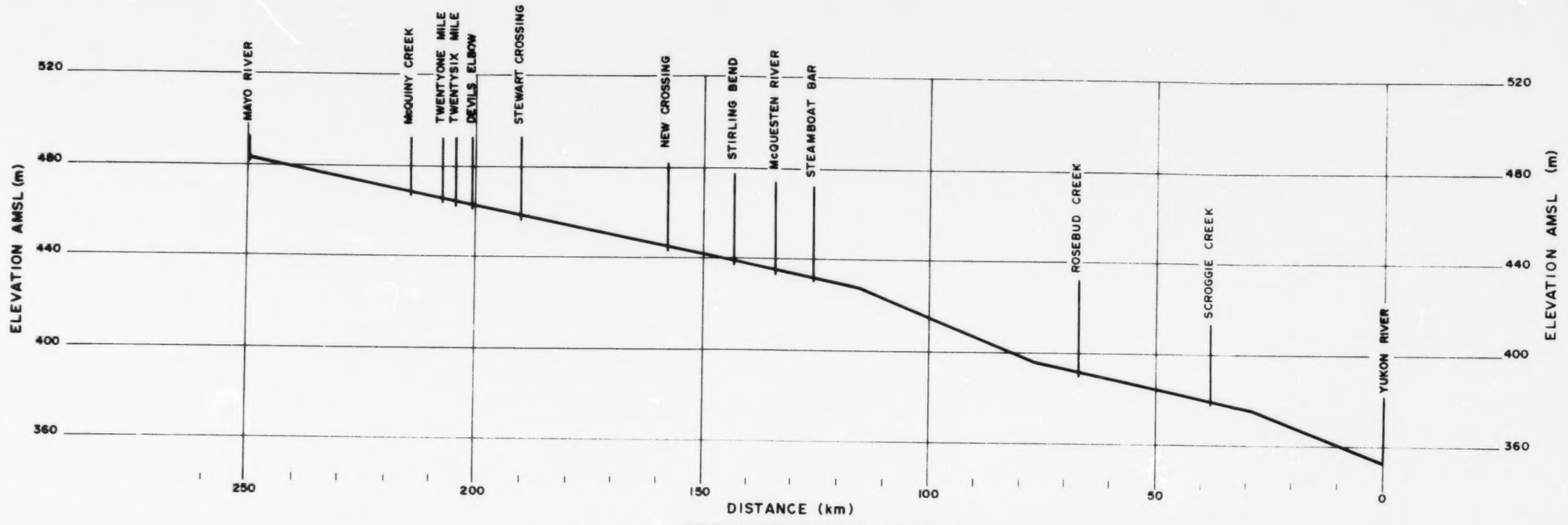
HYDROLOGY WORK GROUP REPORT NO. 1

YUKON RIVER BASIN FLOOD RISK STUDY

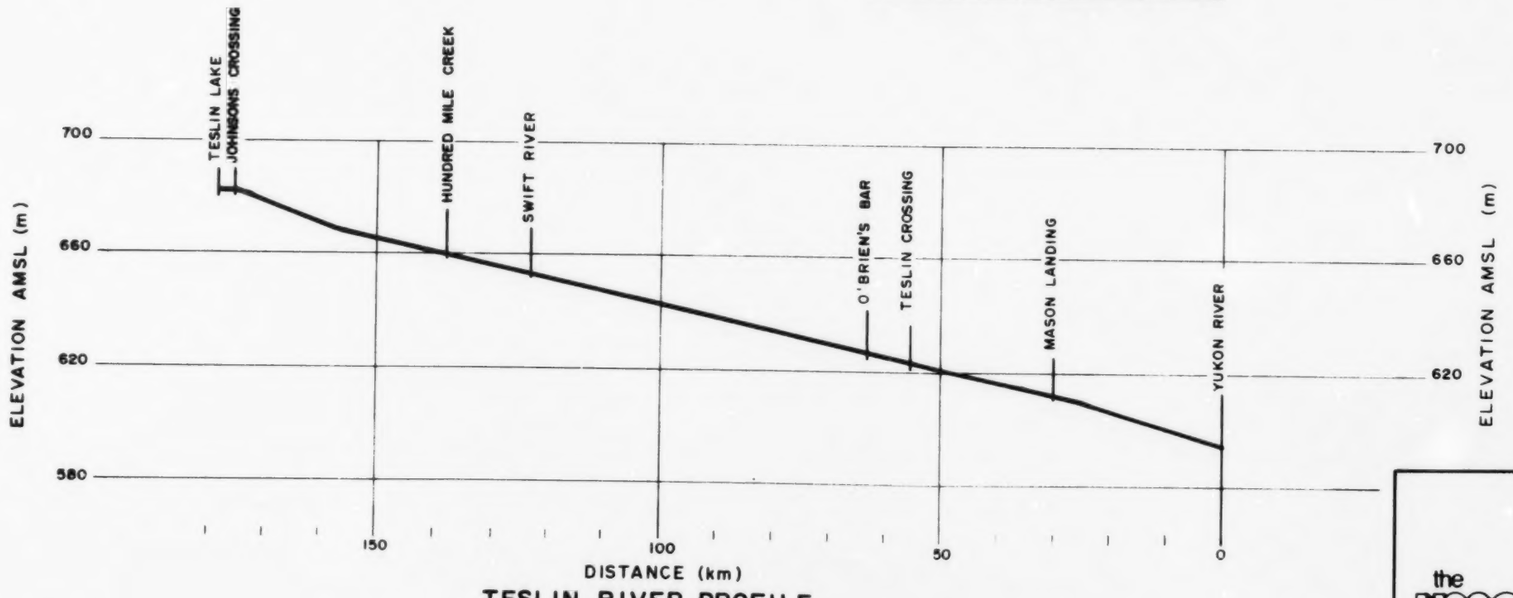
PELLY RIVER PROFILE

Date: October, 1983

Figure 5



STEWART RIVER PROFILE



TESLIN RIVER PROFILE

SCALE
HORIZ 0 10 20 30km (10 5)
VERT 0 20 40 60m (20 10)

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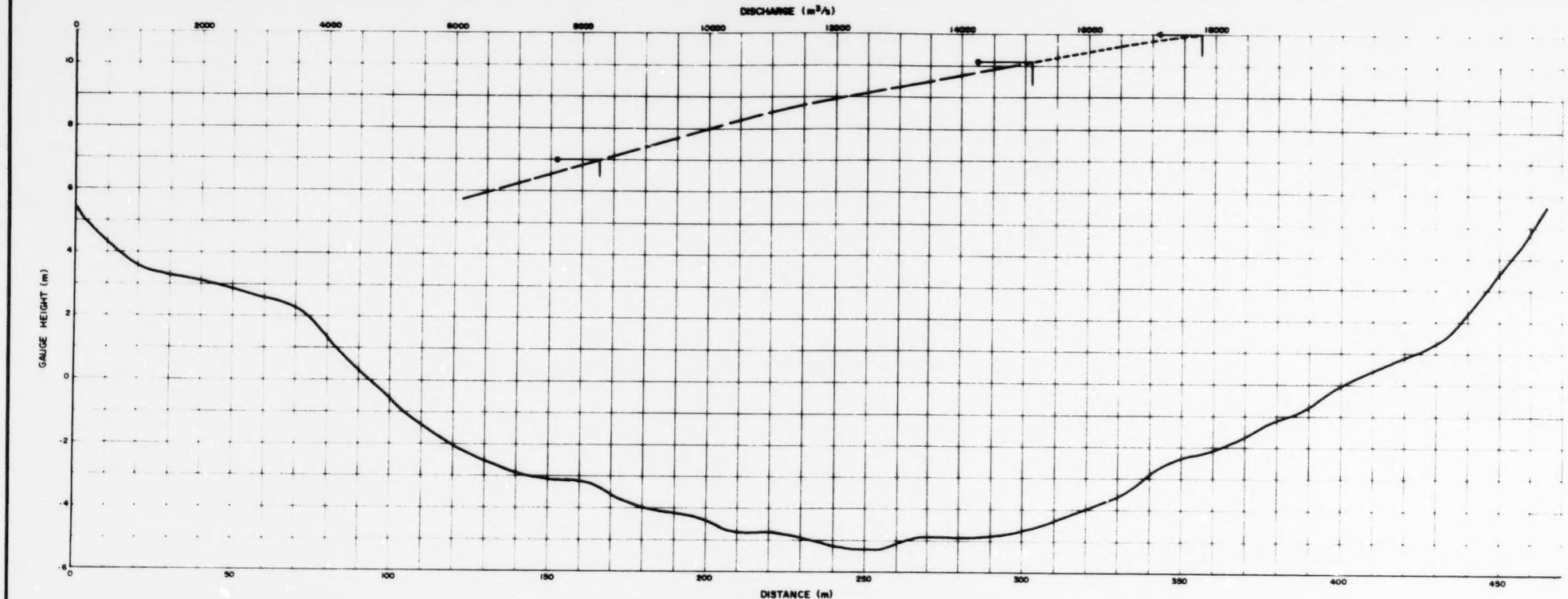
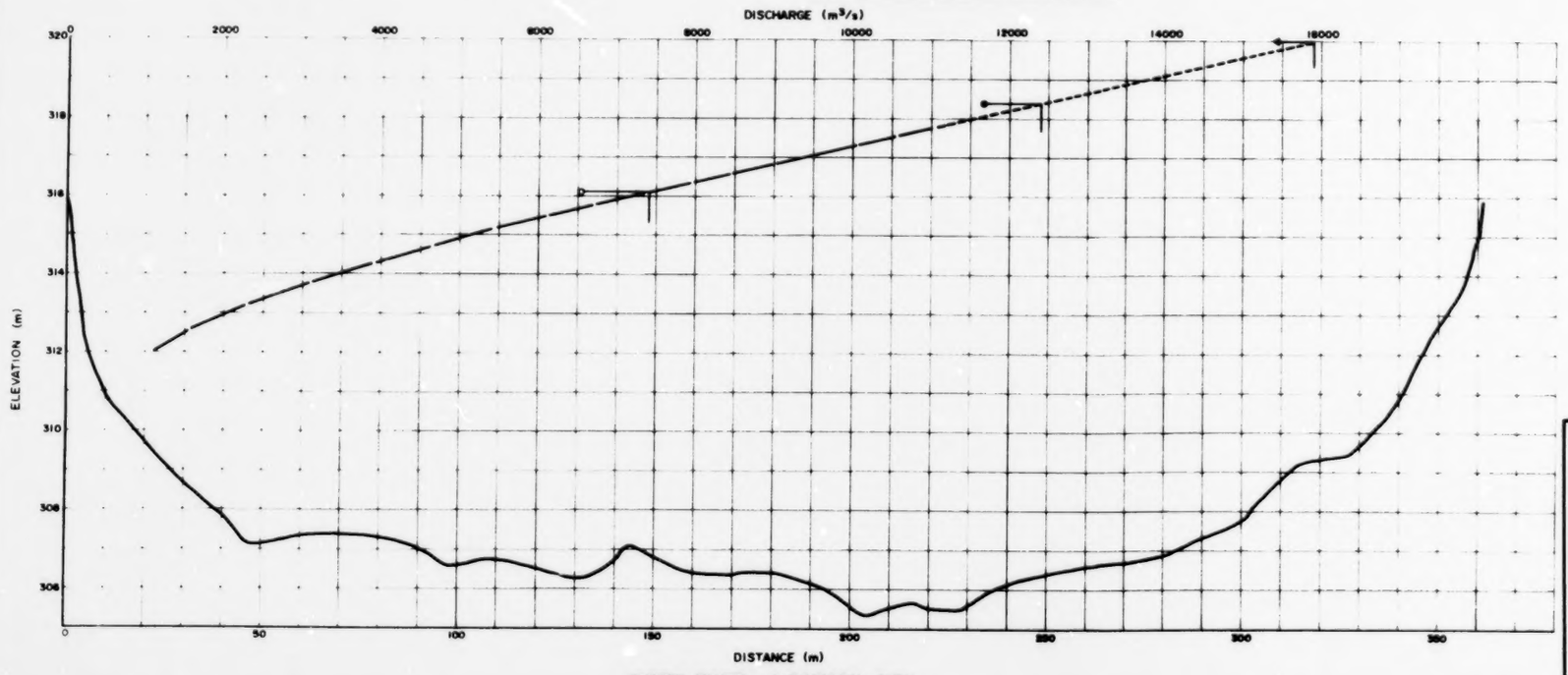
STEWART RIVER AND TESLIN RIVER PROFILES

Date: October, 1983

Figure 6



YUKON RIVER at EAGLE ALASKA



YUKON RIVER at DAWSON CITY

LEGEND:

- RIVER BOTTOM
- WSC RATING CURVE
- RATING CURVE EXTENSION
- MEAN ANNUAL FLOOD LEVEL
- 100 YEAR FLOOD LEVEL
- 100 YEAR REGULATED LEVEL

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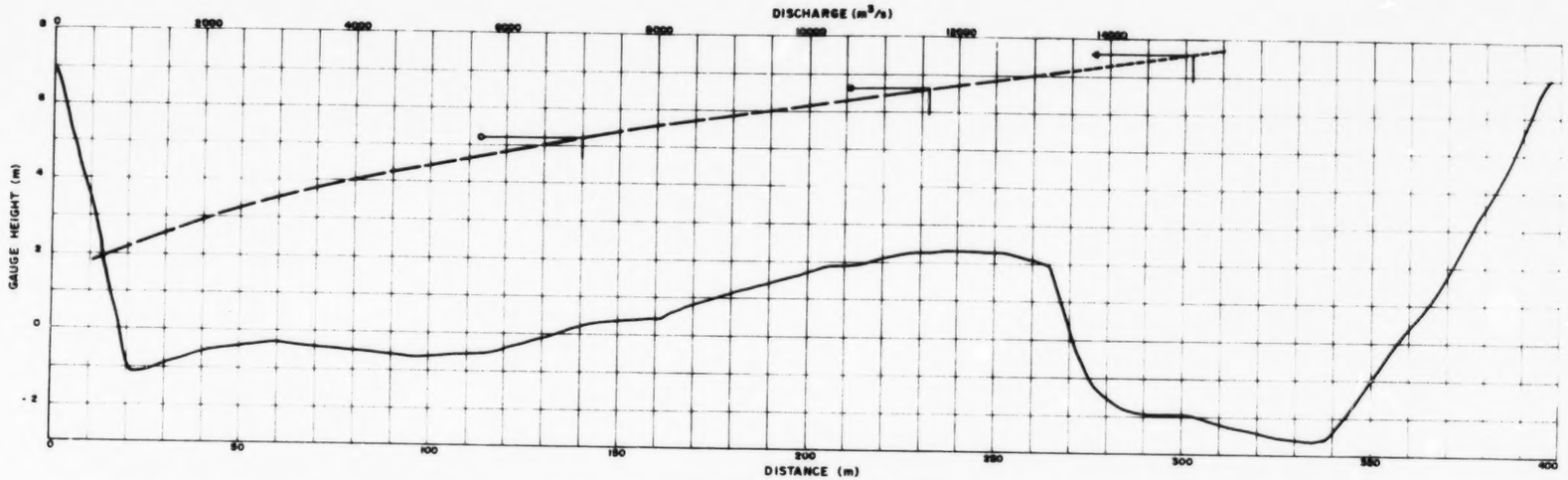
HYDROLOGY WORK GROUP REPORT NO. 1

YUKON RIVER BASIN FLOOD RISK STUDY

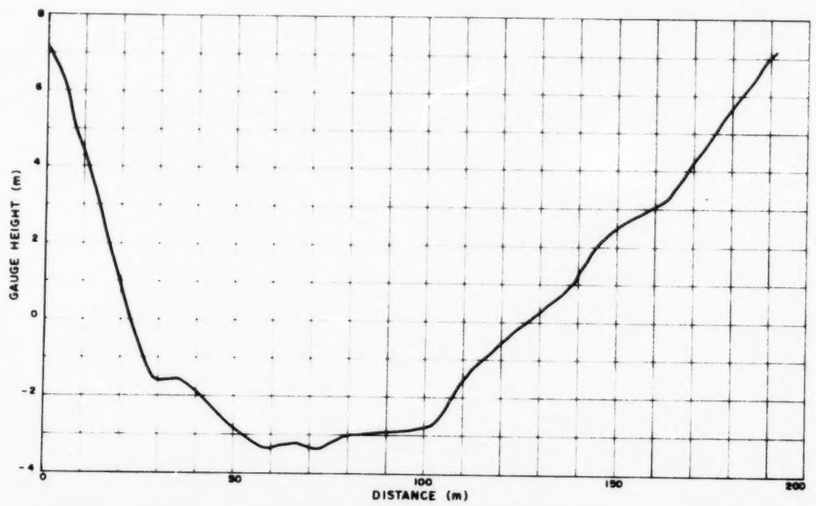
YUKON RIVER CROSS-SECTIONS

Date: October, 1983

Figure 7



YUKON RIVER at STEWART RIVER
(Right Channel)



YUKON RIVER at STEWART RIVER
(Left Channel)

NOTES:

1. STATION DISCONTINUED
2. GAUGE WAS LOCATED AT SETTLEMENT
3. METERING SECTION LOCATED ABOUT 16 km DOWNSTREAM OF THE SETTLEMENT
4. RATING CURVE GIVES THE COMBINED DISCHARGE IN BOTH THE RIGHT AND LEFT CHANNELS

LEGEND:

- RIVER BOTTOM
- WSC RATING CURVE
- RATING CURVE EXTENSION
- MEAN ANNUAL FLOOD LEVEL
- 100 YEAR FLOOD LEVEL
- 100 YEAR REGULATED LEVEL

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INLAND WATERS DIRECTORATE

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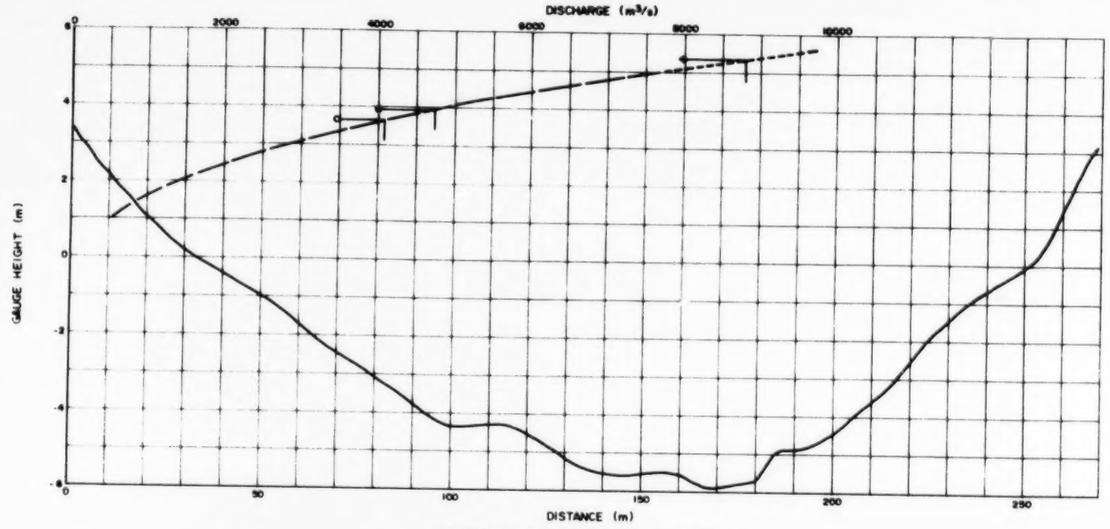
HYDROLOGY WORK GROUP REPORT NO. 1

YUKON RIVER BASIN FLOOD RISK STUDY

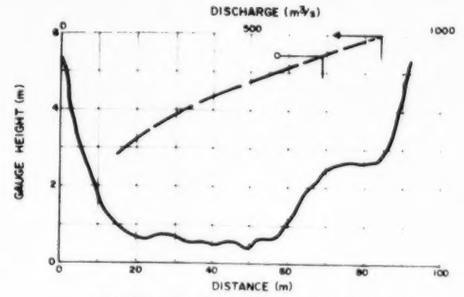
YUKON RIVER CROSS-SECTIONS

Date: October, 1983

Figure 8

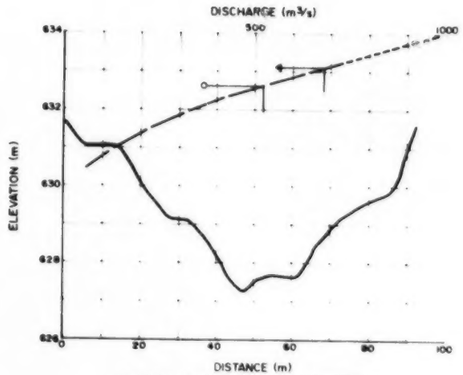


YUKON RIVER ABOVE WHITE RIVER



YUKON RIVER ABOVE FRANK CREEK

YUKON RIVER at CARMACKS



YUKON RIVER at WHITEHORSE

NOTES:

GAUGE ON THE YUKON RIVER ABOVE WHITE RIVER WAS MOVED IN MAY, 1981 AND A NEW DATUM AND RATING CURVE ESTABLISHED. THE INFORMATION SHOWN ON THIS DRAWING CORRESPONDS TO THE GAUGE AT THE OLD LOCATION.

LEGEND:

- RIVER BOTTOM
- WSC RATING CURVE
- RATING CURVE EXTENSION
- MEAN ANNUAL FLOOD LEVEL
- 1:100 YEAR FLOOD LEVEL
- 1:100 YEAR REGULATED LEVEL

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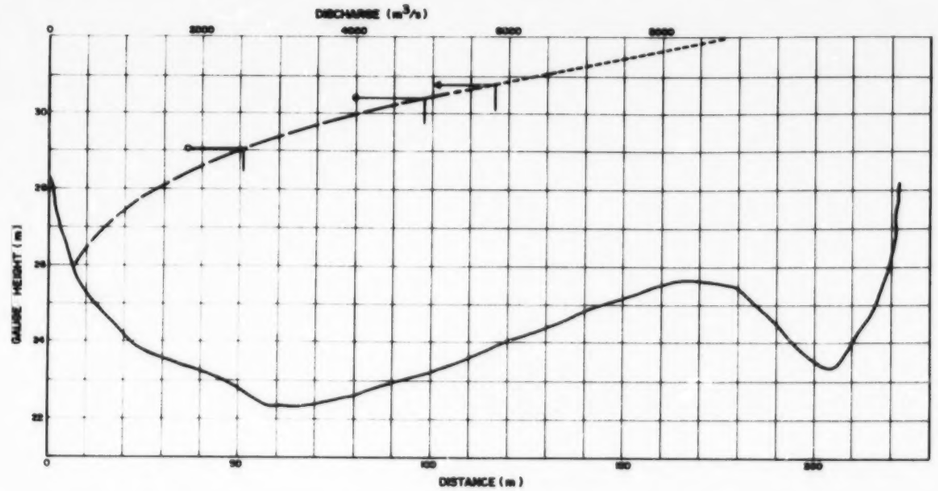
YUKON RIVER BASIN STUDY
HYDROLOGY WORK GROUP REPORT NO. 1

YUKON RIVER BASIN FLOOD RISK STUDY

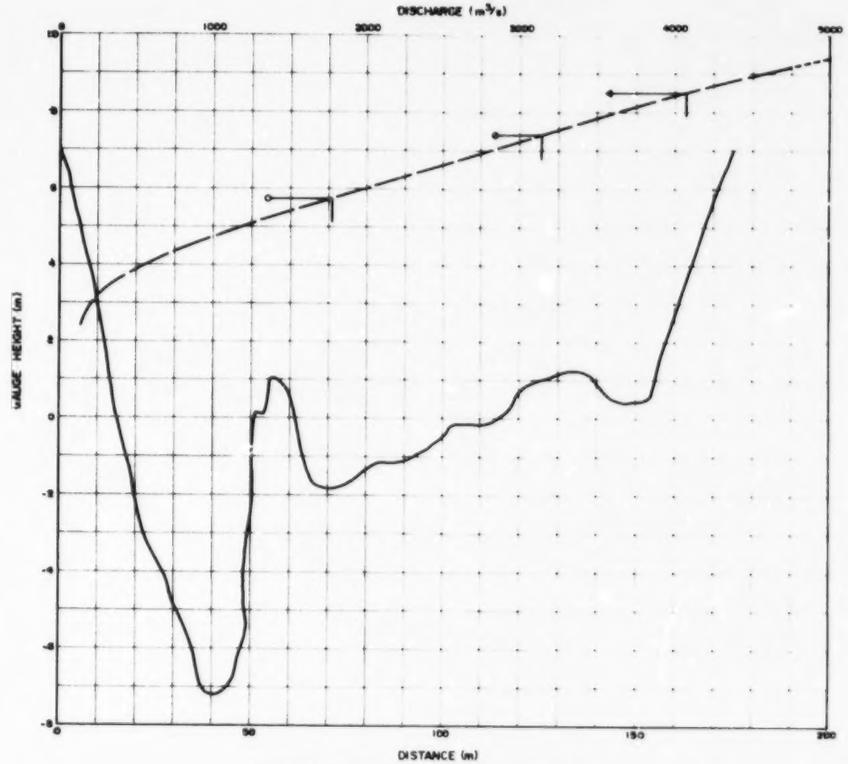
YUKON RIVER CROSS-SECTIONS

Date: October, 1983

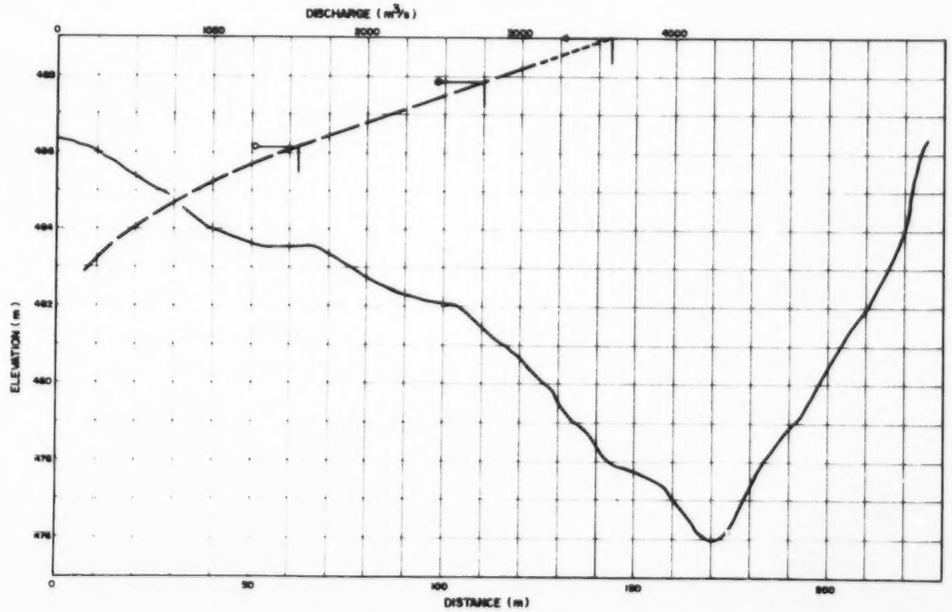
Figure 9



STEWART RIVER at THE MOUTH



STEWART RIVER at STEWART CROSSING



STEWART RIVER at MAYO

LEGEND:

- RIVER BOTTOM
- WSC RATING CURVE
- RATING CURVE EXTENSION
- MEAN ANNUAL FLOOD LEVEL
- 100 YEAR FLOOD LEVEL
- 100 YEAR REGULATED LEVEL

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ENVIRONMENT CANADA
INLAND WATERS DIRECTORATE

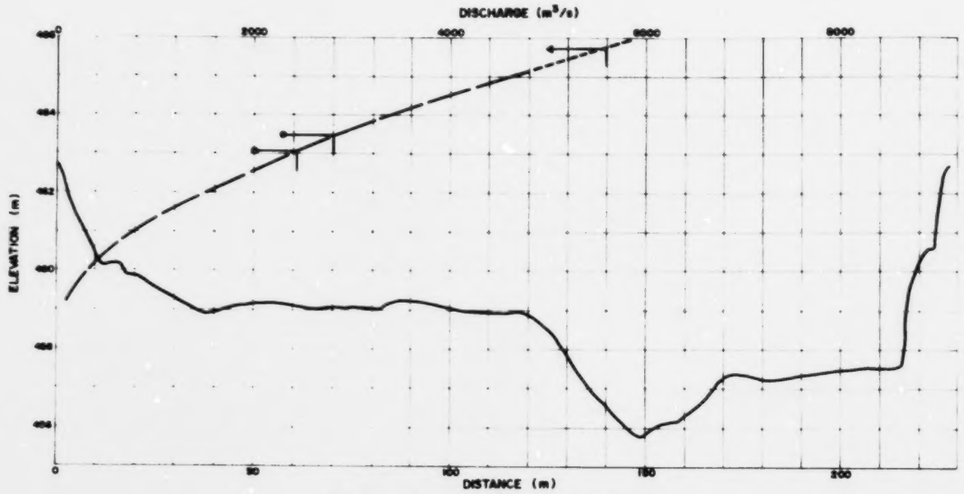
YUKON RIVER BASIN STUDY
HYDROLOGY WORK GROUP REPORT NO 1

YUKON RIVER BASIN FLOOD RISK STUDY

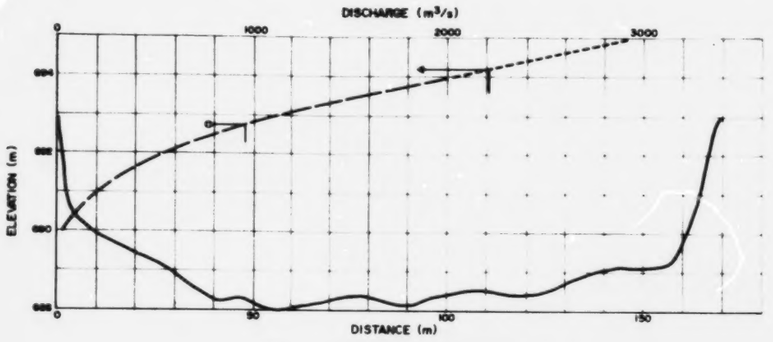
STEWART RIVER CROSS-SECTIONS

Date: October, 1983

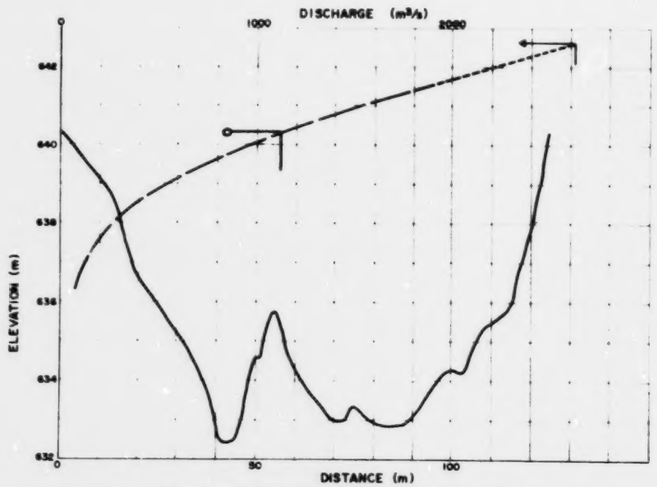
Figure 10



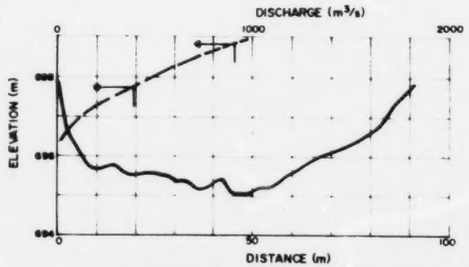
PELLY RIVER at PELLY CROSSING



PELLY RIVER at ROSS RIVER



PELLY RIVER BELOW VANGORDA CREEK



ROSS RIVER at ROSS RIVER

LEGEND:

- RIVER BOTTOM
- WSC RATING CURVE
- RATING CURVE EXTENSION
- MEAN ANNUAL FLOOD LEVEL
- 100 YEAR FLOOD LEVEL
- 100 YEAR REGULATED LEVEL

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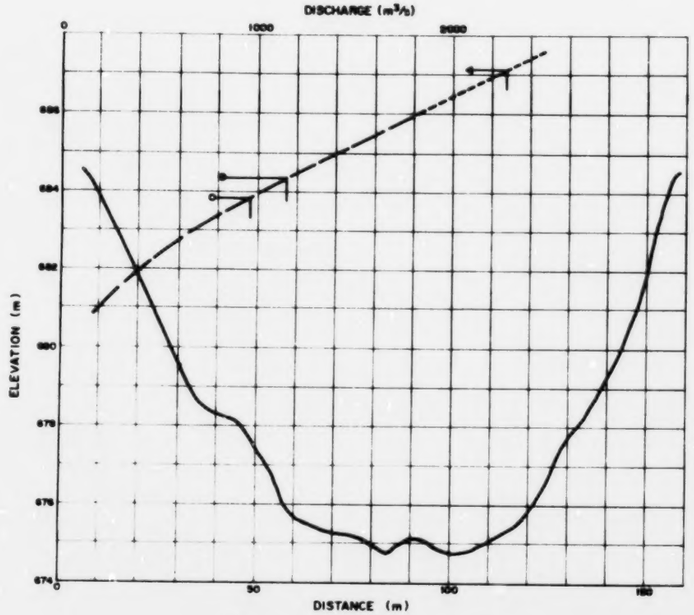
HYDROLOGY WORK GROUP REPORT NO. 1

YUKON RIVER BASIN FLOOD RISK STUDY

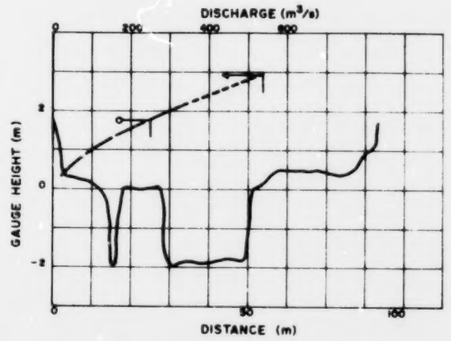
PELLY RIVER AND ROSS RIVER CROSS-SECTIONS

Date: October, 1983

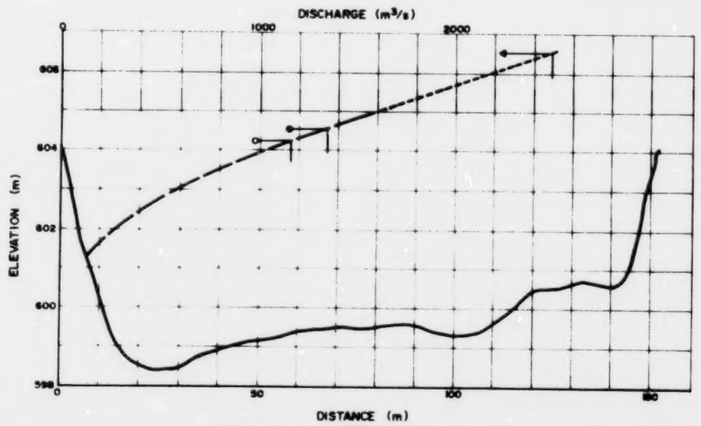
Figure 11



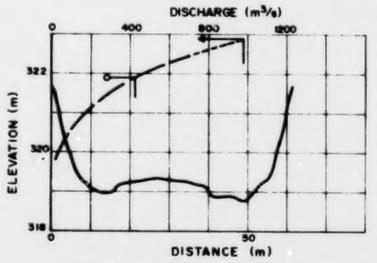
TESLIN RIVER NEAR TESLIN



BIG SALMON RIVER NEAR CARMACKS



TESLIN RIVER NEAR WHITEHORSE



KLONDIKE RIVER ABOVE BONANZA CREEK

LEGEND:

- RIVER BOTTOM
- RATING CURVE
- RATING CURVE EXTENSION
- MEAN ANNUAL FLOOD LEVEL
- 100 YEAR FLOOD LEVEL
- 100 YEAR REGULATED LEVEL

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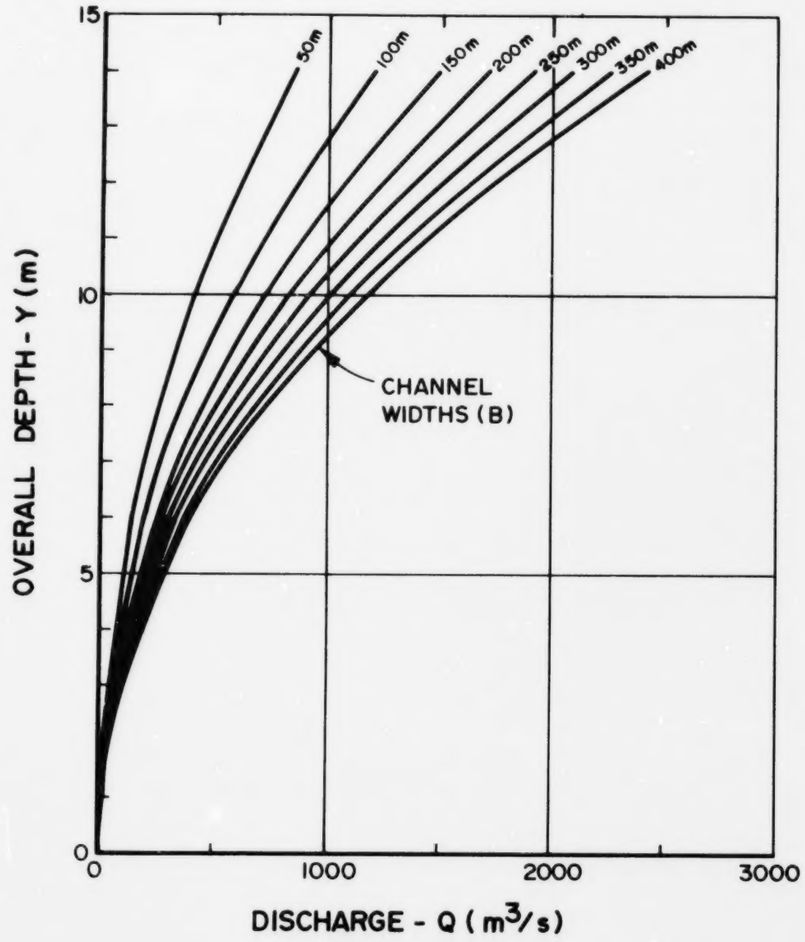
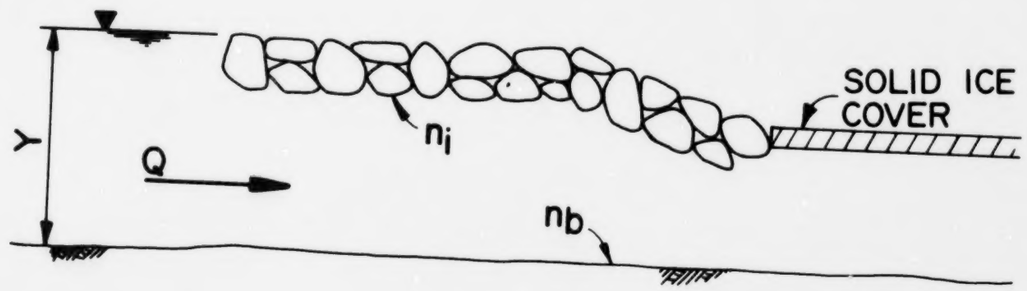
TESLIN, BIG SALMON AND KLONDIKE RIVER CROSS-SECTIONS

Date: October, 1983

Figure 12



ICE JAM STAGE-DISCHARGE CURVES



TYPICAL FLOATING ICE JAM
NOMENCLATURE DEFINITION

$$Q = \frac{0.0408 B^{0.5} Y^{2.16}}{n_O}$$

$$n_O = \left[\frac{n_b^{3/2} + n_I^{3/2}}{2} \right]^{2/3}$$

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FLOW-DEPTH-WIDTH RELATIONSHIPS FOR FLOATING ICE JAMS

Date: October, 1983 | Figure 13